Army Research Laboratory

1999 Annual Review


SURVIVABILITY/LETHALITY
APPLIED RESEARCH
SURVIVABILITY/LETHALITY ANALYSIS

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The U.S. Army Research Laboratory (ARL) is the Army's primary source of fundamental and applied research. Its mission is to provide the Army with the key technologies and analytical support that are necessary to ensure future land warfare supremacy. ARL—with its world-class facilities and eminent workforce, which includes about 1,250 scientists and engineers—constitutes the largest source of integrated science and technology research and development in the Army. The lab has a presence at two major sites, both in Maryland: the Adelphi Laboratory Center (ALC) in Adelphi and Aberdeen Proving Ground (APG) in Aberdeen. ARL also operates unique outdoor facilities at the White Sands Missile Range (WSMR) in New Mexico. In addition, the lab has a long and thriving partnership with the National Aeronautics and Space Administration (NASA) that embodies two ARL divisions. These are colocated with NASA activities in Cleveland, OH, and Hampton, VA. ARL also receives considerable benefit from the Army Research Office (ARO), which was realigned with the lab last year and is located in Research Triangle Park, NC.

This review provides a look ahead. It focuses on ARL's initiatives to support the Army's vision. It presents highlights of the Federated Laboratory (FedLab) program and many recent technical and managerial accomplishments.

Message From the Director

The Army of the future must be a versatile, mobile, lethal, deployable, power-projection fighting force. We at ARL are preparing now to meet the challenges of 2010 and beyond.

We are ever vigilant for creative ideas and innovative technology worldwide to put them to work for the soldier. Our Army Research Office manages the Army's basic science

research grants with academia. We are leveraging the technology investment of the commercial sector and tapping the leading-edge expertise and facilities of universities and private industry. We are working closely with the Training and Doctrine Command (TRADOC) and the robust research and development (R&D) assets of the U.S. Army Materiel Command (AMC) to help develop enabling technologies for the future Army.

As the Army's corporate research laboratory, ARL addresses Army needs across the total spectrum: today's Army of Excellence, Force XXI, Army/Joint Vision 2010, and the Army Beyond 2010. We balance our investment strategy to meet the Army's requirements today and into the future. ARL's focus is on the front-end work—the basic and applied research—which is needed to deliver superior science and technology products for our Army in the future.

The Army After Next (AAN) process generated numerous recommendations for investment in basic research, including terrain- and environment-independent communications and data management, lightweight protective materials, and unmanned vehicles and robotics concepts. Some ARL technology areas identified as potential enablers for the Army Beyond 2010 are

- protection schemes for land systems,
- signature control,
- advanced materials,
- chemical and biological protection,
- alternative propellants and hybrid power systems,
- human and cognitive engineering, and
- fuel and logistics efficiencies.

We are pursuing exciting research at ARL that will greatly enhance the capabilities of the American soldier of the twenty-first century. I am proud and honored to be part of ARL's tradition of excellence, and I invite you to share that pride as you review some recent accomplishments.

Partnering at the Crossroads

One of ARL's main thrusts is to put the best and brightest to work solving Army problems. Within the Army's basic research program, ARL employs a variety of funding mechanisms to support and exploit programs at colleges and universities and in private industry. By leveraging the facilities and resources of academia and industry, ARL complements its internal research efforts and focuses more world-class talent on Army challenges.

FedLab

ARL's Federated Laboratory construct—FedLab—is an innovative approach to integrating external research with internal resources through the establishment of consortia in critical Army technological areas. This approach leverages external expertise, facilities, and technologies in areas where the private sector has both the lead and the incentive to invest.

In January 1996, ARL launched the FedLab initiative, entering into cooperative agreements with industry and university partners to form three consortia: Advanced Telecommunications and Information Distribution, Advanced Displays and Interactive Displays, and Advanced Sensors.

The dynamic feature of the FedLab concept is the cumulative effect of the shared resources, both people and facilities. FedLab members are applying more of their facilities and research talent than is funded by the program. ARL held its third annual Federated Laboratory Technology Symposium to showcase the progress and results of the effort. The symposium was highly successful and resulted in the transition of technologies to the United States Army Intelligence & Security Command (INSCOM) Land Information Warfare Activity and to Advanced Technology Demonstrations.

Outreach

ARL manages 20 Centers Of Excellence. Notable external partners include the Army High-Performance Computing Research Center (AHPCRC) at the University of Minnesota; the Institute for Advanced Technology at the University of Texas (Austin), which is doing hypervelocity phenomena work; and the Information Sciences Center at Clark Atlanta University, with its software engineering efforts. ARL also has cooperative agreements that support microelectronics, including one with the Johns Hopkins University and one with a consortium headed by the University of Maryland. Collaborative programs in materials research are conducted with Johns Hopkins, the University of Delaware, and the Michigan Molecular Institute.

ARL has pursued an active Historically Black Colleges and Universities/Minority Institutions (HBCU/MI) program since the early 1980s. It has been designated by the Department of the Army as the AMC and Army lead for HBCU/MI oversight and proponency.

ARL has six HBCU/MI partners in its FedLab program: the City University of New York, the University of New Mexico Center for High Technology Materials, Howard University, Clark Atlanta University, North Carolina Agricultural and Technical State University, and Morgan State University. In addition, there are four HBCU/MI partners in the AHPCRC: Florida A&M University, Clark Atlanta University, Howard University, and Jackson State University. ARL also has a microelectronics partnership with Howard.

Army After Next

The Army's Chief of Staff asked TRADOC to study issues vital to the development of the Army to about the year 2025. TRADOC created a process of inquiry and critical evaluation that links the development of doctrine, tactics, leadership, and materiel through an annual cycle of workshops and conferences followed by tactical and strategic war games. This cycle culminates in an annual report to the Chief of Staff.

AMC plays an important role in addressing technology and materiel solutions to the operational requirements identified in the process. The AMC Commander selected ARL to lead AMC's support of AAN.

During FY99, ARL supported TRADOC and AMC by initiating the Hybrid Integrated Idea Team (IIT). The Hybrid IIT brought technologists and military art experts together to examine, refine, and provide insights on AAN FY99 capabilities, notional systems, and enabling technologies. The IIT addressed three TRADOC-approved focus areas: Mobility/Survivability/Lethality, Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaisance (C^4ISR), and Combat Service Support. The Hybrid IIT assessments as well as assessments from the Military Operations in Urban Terrain (MOUT) and the C^4ISR IIT were used in direct support of the Spring Wargame and the Technology Materiel Game FY99. The insights gained from these efforts will be transitioned to the process that leads us to the Army Beyond 2010.

The Army Plan of March 1998 reads, in part:

> *We will defer the acquisition of most next-generation systems to focus [science and technology], research and development, and the industrial base on the identification and development of leap-ahead systems to support the AAN.*

With this in mind, the Army set three priorities for equipment modernization: information dominance, physical agility, and lethality and survivability overmatch. Although Army After Next has been superceded by a new Army vision for the Army Beyond 2010, these priorities remain as integral components of that vision. ARL is focusing on technologies that provide warfighters with significantly improved capabilities in all three areas. ARL is focusing its basic science and applied research to meet these challenges; our technology thrusts include

- Lethality and Survivability,
- Human Factors,
- Modeling/Simulation and SMART/SBA,
- Mobility,
- Combat Service Support,
- Sensors, and
- C^4I.

More details of ARL's FY99 contributions to these technology areas are given throughout this review.

Basic Research

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The ARL Basic Research (6.1) program focuses on scientific advances in three areas: overcoming technology barriers (customer-oriented research), exploiting scientific discoveries (opportunity-driven research), and advancing multiple technologies and operational capabilities (both customer-oriented and opportunity-driven research) to achieve the Army's strategic research objectives. These advances are brought about by the collaboration of Army, university, and industry scientists.


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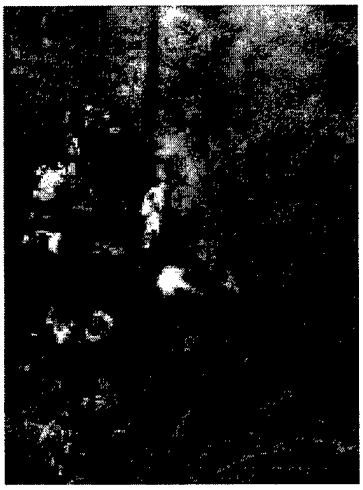
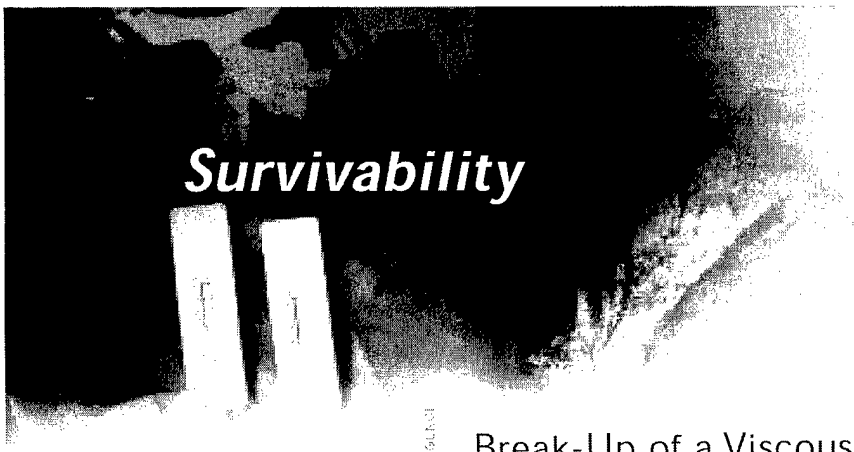
Nanoparticles for Destruction of Toxic Materials

As particles are made smaller, their surface-to-volume ratio increases: a gram of material of density = 1 and consisting of particles of dimensions of 10 nm (10^{-8} m) has a total surface area of 600 m^2. For more than a decade, researchers at Kansas State University have been synthesizing nanoparticles, characterizing their properties, and studying their chemical reactions. This work has shown that nanoparticles of metal oxides adsorb and destroy hazardous compounds.

In the mid-1980s, these researchers found that MgO is very reactive with adsorbed compounds, and by 1990 they had developed new methods to synthesis nanoparticles. The surface areas of aerogel MgO particles are 350 to 500 m^2; those produced by conventional (using aqueous media) means are 130 to 200 m^2, and commercially available materials are 30 m^2. The alkaline earth oxides (MgO, CaO) are basic but safe to handle, while the alkali metal oxides (Na_2O, K_2O) are corrosive, have low melting points, and are very reactive with water. The transition metal oxides, except for Fe_2O_3, are poisonous, and preparation of high surface area materials has not yet been achieved.

Impact: MgO and CaO particles destructively absorb a range of toxic materials, including chlorinated hydrocarbons and organophosphorus compounds. The nerve agent VX and mustard agent can be dissociatively adsorbed and immobilized. Transition metal oxides added to the alkaline earth oxides appear to catalyze decomposition and significantly increase effectiveness. Work is continuing on the synthesis and study of reactions with mixed oxide particles.



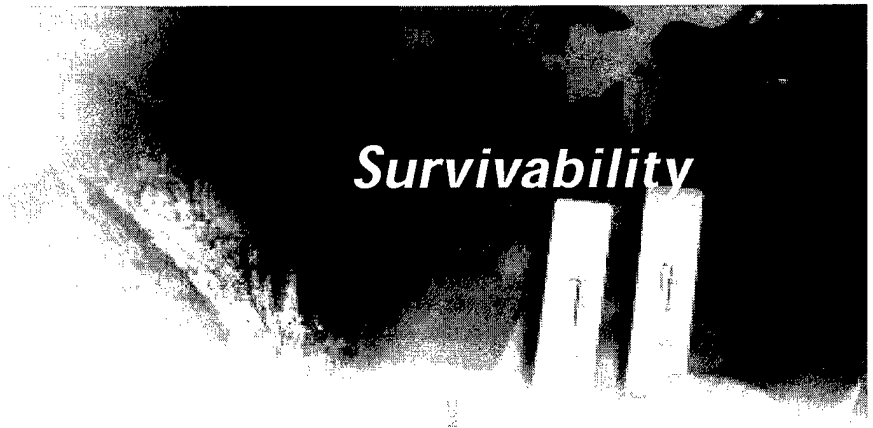


Break-Up of a Viscous Liquid in High-Speed Air Flow: Dispersion of Chemical/Biological Agents From an Intercepted Missile

From the 1950s to the 1980s, Army experimental and field studies of the break-up of thin and thick liquids in high-speed air flow led to a partial understanding of the mechanisms of the break-up, the size of the resultant liquid droplets, and the amount of vapor that appears after break-up. However, in these studies, up to 60% of the original mass could not be accounted for.

Under an ARL grant, researchers at the University of Minnesota, have identified flash vaporization—the cavitation of a superheated liquid under low pressure—and the subsequent condensation as the mechanisms that form this mist. Flash vaporization occurs in the hot, low-pressure liquid on the lee side of the drop. Low leeside pressures are produced by the rarefaction of the gas, the acceleration of the drop, and the high tensions generated by rapid stretching of threads stripped from the surface of the original liquid mass. High temperatures are produced by heat transfer from the hot gas behind the shock to thin drop filaments and by viscous heating due to rapid deformation. Researchers have obtained detailed information on the fragmentation process by analytical and computational methods and by experiments in extremely low-pressure shock tubes. An increase in viscosity (due to the presence of chemical/biological agents) results in an increase in *threading*, which increases the droplet size and mass in droplet versus that in vapor.

Impact: This research is leading to an improved capability to predict the dispersion of chemical and biological agents spilled from incoming theater missiles when they are intercepted. Under the guidance of the Army's High Altitude Working Group, shock tube expertise is being transferred from the University of Minnesota group to an Army contractor to test live chemical and biological agents. The Edgewood Research, Development and Engineering Center will use the results as input to computer codes that simulate how the vapor and droplets disperse after the interception of a missile. This knowledge is important for planning when to intercept the missile and which areas to evacuate.



Cellular Olfactory Molecular Recognition

The discriminatory capacity of the mammalian olfactory system is such that thousands of volatile chemicals are perceived as having distinct odors. As part of a Multidisciplinary University Research Initiative at Cal Tech on olfactory sensing, sponsored by Office of the Secretary of Defense, researchers at Harvard Medical School have used a combination of calcium imaging and single-cell reverse transcriptase-polymerase chain reaction biotechnology to identify cellular olfactory molecular recognition elements, or odorant receptors (ORs), for odorants with related structures but varied odors. They found that one OR recognizes multiple odorants and that one odorant is recognized by multiple ORs, but that different odorants are recognized by different combinations of ORs. Their studies indicate that the olfactory system uses a combinatorial receptor coding scheme to encode odor identities, and that slight alterations in an odorant can change its *code,* potentially explaining how such changes can alter perceived odor quality.

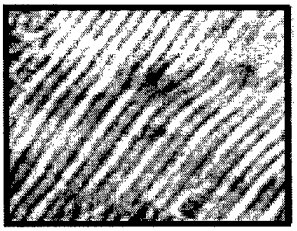
Previous research has provided experimental evidence for the existence of about one thousand types of structurally distinct odorant receptors. These researchers had already identified a multigene family encoding these diverse odorant receptors expressed by olfactory sensory neurons in the nose. These studies establish an understanding of the fundamental basis for mechanisms operating in the sense of smell, with the long-term aim of providing sufficient scientific information and technological insight regarding olfactory processes.

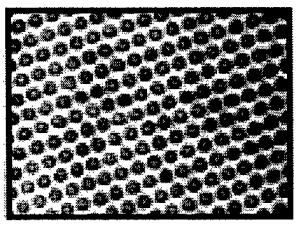
Impact: These studies will affect noninvasive medical diagnostics, analysis of food, sensing contamination in individual soldier protective ensembles, environmental monitoring, sensing the presence of enemy personnel and weaponry in hostile territory, localization of hidden enemy assets, detection of explosives both in operations other than war and for counterterrorism, and sensing for treaty compliance, among others.

Self-Assembling Polymers for Permselective Chemical and Biological Agent Protective Materials

Researchers at the University of Massachusetts, Amherst, are investigating newly synthesized polymers that have multiple grafts (5 to as many as 10 or more) per backbone. They have investigated the effects of both regularly spaced branching and randomly spaced branching on morphology and on the degree of long-range order in the materials. The results indicate that the materials generally form the morphologies predicted by their corrected Milner morphology diagram, and there are clear and interesting effects of molecular architecture on long-range order. First, the materials with regularly spaced grafting points form much better long-range order than those with a similar number of randomly located grafting points per molecule. Second, in a series of materials with regularly spaced grafting points and the same overall component volume fractions, as the number of grafting points per molecule is increased the materials progressively loose long-range order. The group has made some progress in quantifying this long-range order effect by measuring grain size and correlating a decrease in grain size with an increase in graft points per molecule. Third, they have found that, all things being equal (number of graft points per molecule, regular or random graft placement), lamellar morphologies always form better long-range order than spheres, cylinders, and bicontinuous structures. While disordered packings of spheres and cylinders can fill space to uniform density, sheet-like structures must order parallel to one another to be able to effectively fill space. Thus, graft copolymer materials that form lamellar structures essentially template their own long-range order. They cannot fill space unless they order, and the energy penalty for not filling space to uniform density is very high.

Impact: This research is coupled to an ARL program focused on developing new materials for chemical and biological warfare agent protection, By controlling the molecular weight of the diblock starting material, the tube dimensions may be controllable to a high degree of accuracy. Control over nanometer ordering and dimensions is important for developing flexible, semipermeable materials that are barriers to chemicals and chemical agents, while allowing air and water to penetrate, thus making it safe and comfortable for the wearer.





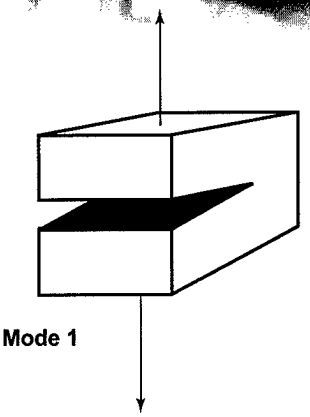
Delamination Characterization of Composite Materials

The goal of this research is to develop standardized test techniques. Currently, several different test techniques are used for determining failure criteria for polymer matrix composite materials under Mode I, Mode II, Mode III, and Mixed-Mode loading schemes. This has resulted in inconsistent failure criteria.

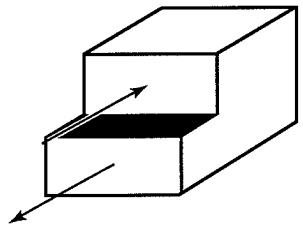
Researchers are using international interlaboratory round robin testing programs, coordinated through the American Society for Testing and Materials (ASTM) and VAMAS, to study and compare various testing methods. The round robin results will be used to develop draft standards that will then be balloted through ASTM Subcommittee D30.06 and Committee D30. This work will be done with the international testing community to develop internationally accepted test methods through the International Organization for Standardization (ISO).

Through this effort, the double-cantilevered beam (DCB) test standard has been published as ASTM Standard D5528-94a in Standards Volume 15.03. ISO has balloted the DCB draft as a Draft International Standard (DIS). A draft ASTM standard for the Mixed-Mode Bending test was balloted and has been revised. The revised draft has been balloted at the Committee D30 level and results were to be presented at the May 1999 ASTM meeting. An exploratory round robin has been initiated for the new 4ENF Mode II test, a four-point bending version of the ENF test. The exploratory round robin will allow labs to gain experience and examine the robustness of this test before a decision is made on which Mode II test(s) to consider for a new ISO work item.

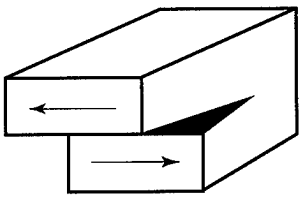
Impact: A standardized DCB test technique provides reliable Mode I fracture toughness data for use in predicting damage tolerance and comparing the performance of different materials. Because most delamination is a result of a combination of Mode I, II, and III loading, Standards for Modes II, III, and Mixed-Mode testing are also necessary.



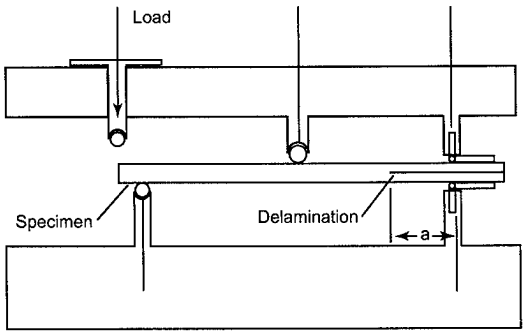
Mode 1



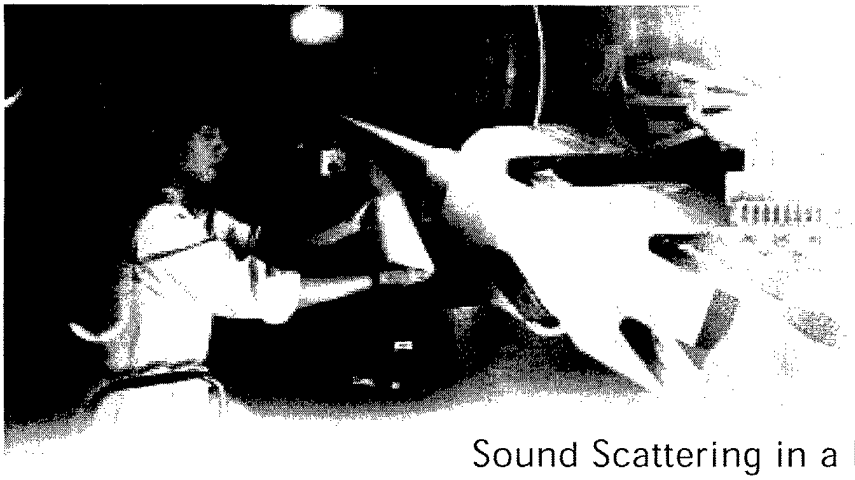
Mode 2



Mode 3



Mode 4



Sound Scattering in a Moving Turbulent Atmosphere

The propagation of sound through the atmosphere is a natural and primary means for the detection, identification, and tracking of moving vehicles. Sound scattering in the air is caused by fluctuations in temperature, C_T^2, and winds, C_v^2. Most Army models of sound propagation are based on a still or uniformly moving atmosphere with a known vertical profile of temperature.

Under an ARL grant, the New Mexico State University has developed an improved theory of the effects of turbulent wind fluctuations on acoustic signals and verified it with laboratory data. This research has led to expansions of the parabolic wave equations to examine the effects of wind turbulence on acoustic signals in an inhomogeneous atmosphere.

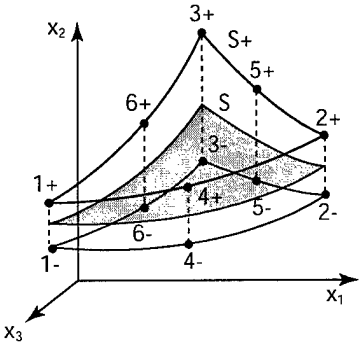
Impact: The effects of turbulent scattering by the wind must be considered in acoustic remote sensing of the atmosphere. Algorithms for detecting, tracking, and identifying sound sources on the battlefield can now be improved to allow for a more realistic inhomogeneous atmosphere.

Three-Dimensional Modeling and Simulation of Kinetic Energy Penetrators and Armor Materials During Ballistic Impact

A multitude of Army materiel, such as rotorcraft, tactical missile structures, ground vehicle armor, and penetrators are subjected to impact loading conditions that span the spectrum of velocities, impulses, and temporal and spatial scales. Vulnerability assessments and the design and development of innovative mobile and high strength systems have been severely hampered by the lack of full-field predictive tools and models that can be used to assess the response of systems subjected to severe loading conditions and changing environments.

The California Institute of Technology, with ARL support, has developed new 3-D dynamic computational cohesive fracture formulations to characterize and predict the ballistic performance of antiarmor penetrators and the impact and failure of high strength armor systems. Fully automated adaptive meshing for 3-D Lagragian finite-element computations and contact and search algorithms have been developed to resolve complex and multiple interactions that result from the creation of fracture surfaces and fragments. The 3-D adaptive meshing has been used to provide the capability of accurately accounting for multiple fracture sites. This is in contrast to other methods, which require the insertion of special interfacial elements at the outset of the analysis. This approach adaptively creates new surfaces based on nonlinear 3-D cohesive fracture models. The contact algorithms that have been developed have the capability of dealing with the large number of complex multibody collisions and multiple failure paths normally associated with fragmentation and crack nucleation and propagation.

Impact: This research provides new methodologies and design guidelines for the prediction of material failure mechanisms, such as structural impact, penetration, and collapse. These predictions can be used to assess and analyze the ballistic performance of kinetic energy penetrators and armor systems. Events that are difficult, if not impossible, to experimentally investigate, such as crashworthiness and fragmentation, can be accurately simulated. These tools and formulations can also be used for the development of innovative multifunctional heterogeneous systems, such as new and improved personnel and asset protection platform and lethal target defeat systems. Furthermore, since design and material variabilities can be fully explored, reductions of design cost and prototype development and accurate life-cycle estimates can be realized.



Twelve-noded cohesive element

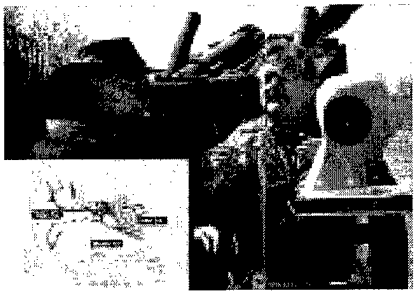
The Ear Model

The Auditory Hazard Assessment Algorithm-Human (AHAAH) is a theoretically based mathematical model of the ear implemented on a PC platform. This model represents a unique approach in the area of auditory hazard assessment. Impulse noise criteria require the use of hearing protection that degrades combat effectiveness by deafening the soldier to potentially useful auditory information in combat situations. By utilizing the predictive capability of the model, the noise profile of new (or modified)

weapons can be assessed and optimized in a cost-effective manner without expensive field-testing. The model can also be used to develop improved hearing protective devices (and technologies) that shield soldiers from harmful noise impulses, while preserving auditory functioning and, therefore, maintaining enhanced situational awareness.

During FY99 the American National Standards Institute (ANSI) accepted the model as a draft standard for impulse noise assessment. The model also was transitioned to the automotive industry. Here it is being used to assess air bag hazards to aid in the development of an improved air bag. Collaboration with other groups offers the opportunity to expand the modeling effort and the technology to a variety of industrial settings. This work was recognized with an Army Research and Development Award.

Impact: The model allows the development of more effective weapons while maintaining soldier safety and situational awareness and, therefore, increasing survivability and lethality.

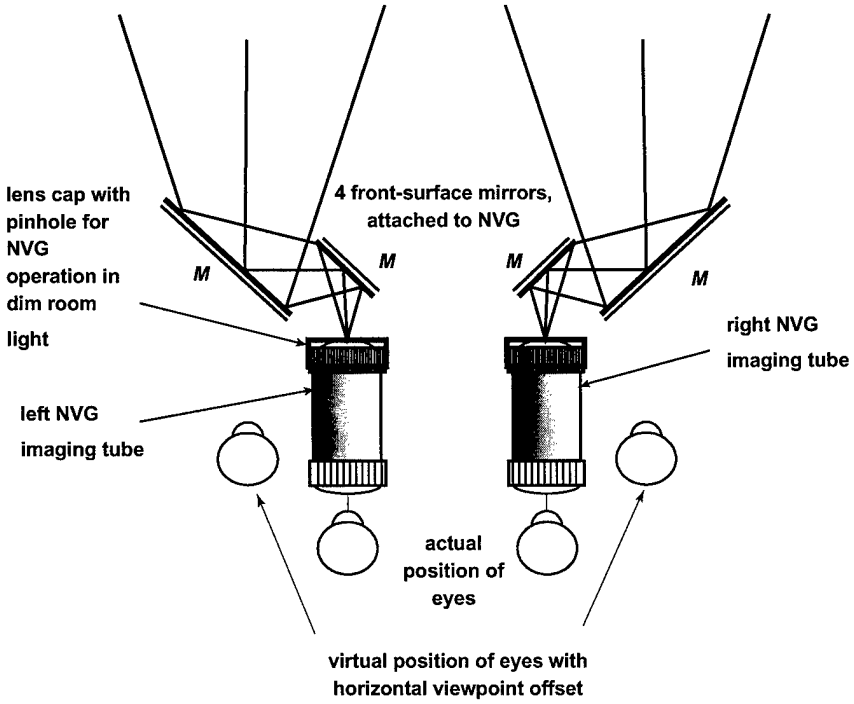


Design Issues in Display Technology

Helmet-mounted displays, night-vision devices, and other visual displays work to extend the soldier's sensory perception, but they must be designed properly to maximize performance. The incorporation of findings from basic perceptual studies and the understanding of human factors in design and use provides guidance to designers of new equipment.

For a number of practical reasons, the sensors on the front end of night vision goggles (NVGs) sometimes must be displaced relative to the soldier's eyes. ARL conducted a study to determine the side effects of sensor-viewpoint offsets, such as hyperstereo, on the perceptual-motor performance of soldiers wearing night-vision goggles. The results indicated that wearing NVGs with hyperstereo viewpoint offsets resulted in a statistically significant increase in the magnitude and direction of errors in throwing grenades compared to nonhyperstereo viewpoint offsets.

Impact: These studies provide human factors guidance to equipment designers. Improved equipment design will result in greater soldier performance, survivability, and sustainability.



Cognitive and Perceptual Variables in Target Acquisition

The ability of soldiers to acquire (detect, recognize, and identify) targets is a basic requirement for the Army's superiority on the battlefield. The accuracy with which we can predict that ability is directly related to the correct assessment of strategies and logistics of battlefield scenarios. To do this we need to better understand the process of search and target acquisition. This includes an account of cognitive and perceptual factors in soldier performance. The target acquisition models that are used to assess battlefield scenarios are not sufficiently accurate in their predictive ability. These models emphasize the physical characteristics of the scene, but do not adequately incorporate human cognitive and perceptual processing factors. The Army needs the ability to accurately predict soldier target acquisition performance to improve the estimates of survivability and lethality and promote the design of improved sensor systems. By incorporating empirical data from studies that explore specific cognitive and perceptual variables using human observers, we can reduce the variability in model output and improve its predictability for combat simulations.

FY99 efforts demonstrated the effect of visually directed selective attention on target acquisition performance in naturalistic scenes. Future studies will examine the effects of multisensory (auditory and visual) information on target acquisition.

Impact: Results from these studies will be used to accurately assess the contribution of cognitive and perceptual factors on target acquisition and to incorporate these factors into existing target acquisition models.

Simulating Human Motion

The Army studies human physiology and performance as part of its mission to enhance the war-fighting capabilities of the soldier. The goals of these studies include optimizing human performance through advanced equipment design and training, minimizing the risk of injury and the time and cost of developing and acquiring new equipment, and predicting human performance in a range of scenarios.

A new software tool, PeopleShop, for populating simulation-based scenarios was developed under an ARL SBIR Phase II contract. The tool is ideal for training, mission planning, urban simulation, and real-time visualization.

MODELING/SIMULATION and SMART/SBA

PeopleShop is specialized for scenarios that involve human activity and interactions, especially in and around buildings. The contractor has worked with the U.S. Army Soldier Systems Command to develop a digital biomechanics laboratory (DBL)—an advanced system for simulating humans performing useful tasks under novel conditions. Biomechanical simulations will allow researchers to test products under realistic conditions faster and cheaper than with physical prototypes and live subjects. The DBL is designed to help researchers study the mechanics and principles of human performance and injury.

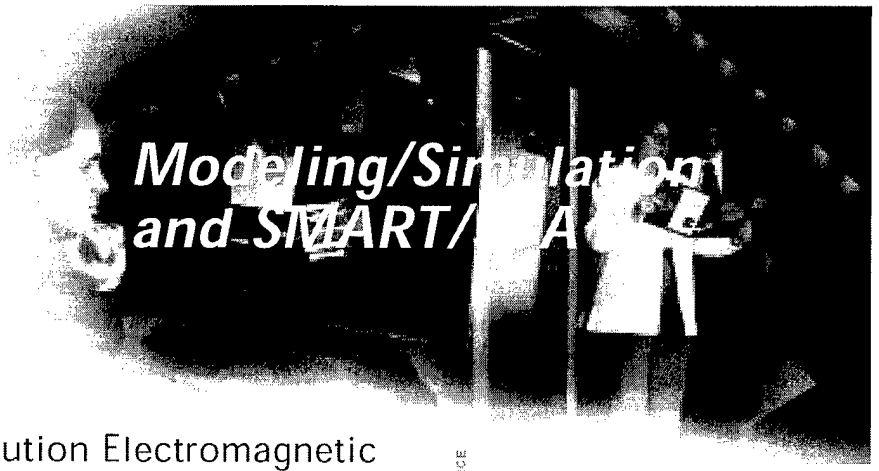
Impact: This tool will lead to applications for evaluating the effectiveness of soldiers' clothing, footwear, chemical/biological gear, other equipment (especially backpacks), and movement strategies. With the creation of improved equipment design and training strategies, the simulation tools under development will help the Army enhance the capabilities of soldiers to carry loads. Other applications include adding simulated humans to ballistic vulnerability/lethality real-time visualization training systems.

Software Tools for Parallel Computing

The development of computational algorithms and software tools for performing design and analysis of advanced weapon components requires efficient use of available computer power. To minimize required computer time and maximize efficiencies of computer architecture, modern analysis strategies consider parallel computing environments using many single mode processors (SMPs) for adaptive mesh refinement schemes. The barrier to accomplishing these objectives focuses on having the computer automatically partition the problem, balance workload distribution among the computer nodes, and refine partitioning as mesh is refined to maximize the network performance.

Research supported by ARL at Rensselaer Polytechnic Institute has been investigating algorithms and software tools to support adaptive computation in a heterogeneous parallel computing environment. This research is directed toward using detailed information about the computer architecture to generate strategies for automatically partitioning the problem, balancing the workload among computer processors, and predicting changes in partitioning due to adaptive mesh refinement to obtain the performance that a machine is capable of with minimum input from a user. A simple example of a finite element mesh would be a parallel environment consisting of a pair of two-way SMP workstations connected by a network and the partitioned mesh. In this example, the Rensselaer partition model would partition the mesh into six pieces that are assigned to four processes, which in turn are assigned to the two machines. The ability to assign multiple partitions to a process can be used to enhance cache hits, to allow efficient out-of-core calculations, or to allow efficient migration between partitions after adaptive mesh refinement.

Impact: Preliminary versions of these tools have been tested on a model muzzle brake fluid flow problem for ARDEC Benet Labs and on a helicopter rotor aerodynamics problem for AMCOM. Such tools will permit Army scientists and engineers to more easily port software to new computer architectures as they become available. They will also permit the use of adaptive methods on the challenging science and engineering problems that need to be solved to develop future weapons systems. Such methods permit the most efficient use of available computer resources.

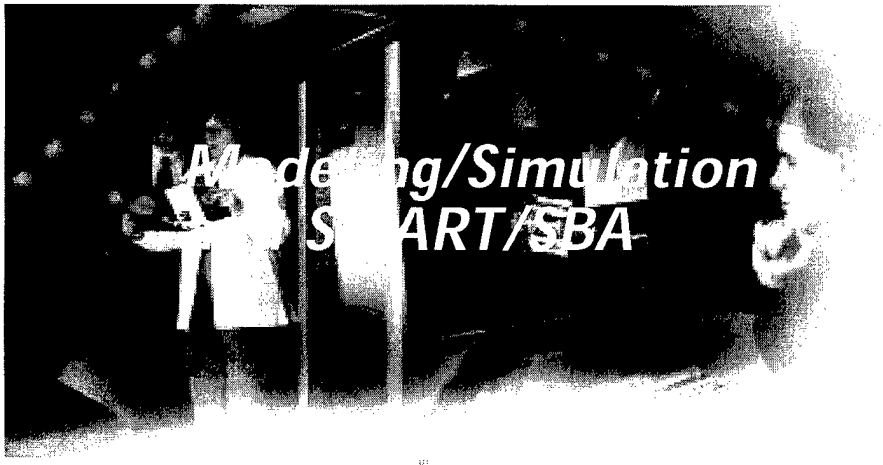


Advances in Multiresolution Electromagnetic Modeling and Simulation Techniques

As a result of ARL-sponsored research at the University of Michigan, Duke University, and EMAG Technologies, Inc., new approaches to the modeling and simulation of electromagnetic (EM) structures and circuits have been formulated that reduce computational requirements by several orders of magnitude and enable the simulation of new problems previously inaccessible by computer modeling. The ability of wavelet families of functions to naturally describe different levels of resolution is exploited by formulating methods of moments (MoM) and finite difference time domain (FDTD) techniques in terms of wavelet basis functions.

By introducing wavelet functions in both time and space at each point in the finite difference grid, it is possible to calculate with great precision fields in regions where the fields are high or changing rapidly and to reduce the resolution in regions where the fields are small and changing slowly. Furthermore, it is easy to do this in a manner that is adaptive in space and time. It is easy to follow a propagating pulse with calculations done at a very high level of resolution, while conserving run time and memory in the regions that the pulse has passed over or not yet reached. This method is also easily suited to combining highly nonlinear device calculations directly with the EM calculation, introducing the capability to globally model EM/device circuits self-consistently. The MoM technique has been formulated in a hybrid MoM/FEM (finite element method) parallelized code for complex electromagnetic circuits and antenna arrays for the DoD High Performance Computing Initiative. This technique recently completed a highly successful beta test and is now available on all DoD HPC computer systems. The multiresolution MoM technique has also been combined with new concepts in macromodeling, sparse matrix analysis, and accelerated hybrid genetic algorithms in a powerful antenna array/feed structure commercial design code of unprecedented capability.

Impact: By reducing design time and by increasing the density of complex microwave and millimeter wave integrated circuits (MMIC's and MIC's) these techniques will significantly reduce the size and cost of MMIC's for sensors and communications applications. Cost and circuit size are major barriers to the use of millimeter wave circuits for military systems applications in communications and sensors. Millimeter wave systems offer substantial potential advantages of high resolution using small antenna arrays for vehicular, aircraft, and missile radar and communications applications and of all-weather sensing at higher resolution.

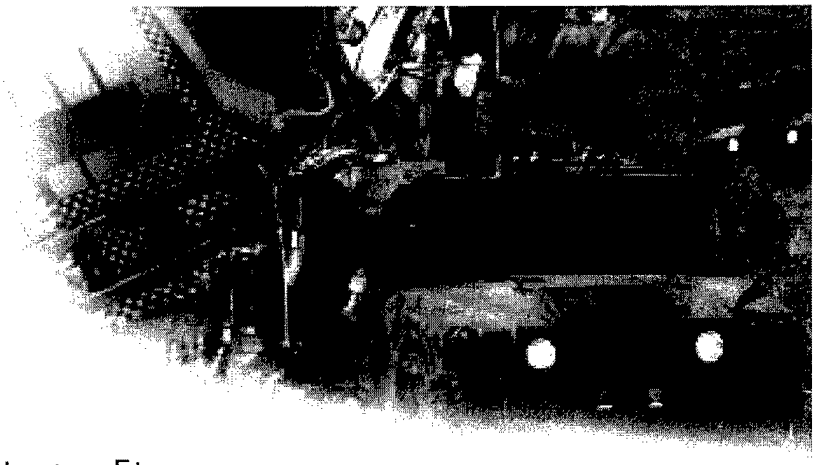


Modeling of Flows in Microelectromechanical Systems Devices

Future actively controlled engine combustion systems will incorporate microelectromechanical systems (MEMS) for precise control of combustion dynamics. Understanding and design of flows in these microscale devices are not possible using currently available analytical tools.

A new Lattice Boltzmann (LB) model has been developed for efficient simulations of very small MEMS device flow fields by researchers at the Georgia Institute of Technology under an ARL grant. The advantage of LB methods is that they can be extended to the slip and the near-continuum regime allowing access to both micro- and nano-flows. The new LB solver is much more efficient in comparison with finite-volume schemes: a 321 x 325 lattice simulation takes only 12 hours on a single processor SGI Origin 2000 compared with over 5 days for an equivalent finite-volume solution. The model has been applied to the study of a fuel injector that is excited by two synthetic jets. The methodology will be extended to multiphase, reacting flows.

Impact: MEMS devices are expected to be important sensor/actuator components in advanced, controlled combustion engines for future Army propulsion systems. Efficient design of these devices will be enabled by this new simulation capability.



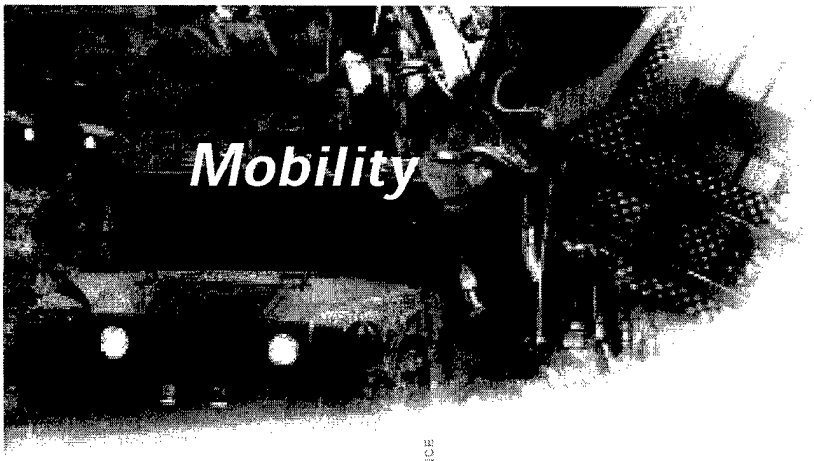
Modeling Diesel Engine Injector Flows

High-performance diesel engines require high pressure/velocity fuel injection systems that are durable and perform consistently over the lifetime of the engine. Current designs tend to have high wear due to internal flow cavitation that leads to poor fuel economy and excessive emissions.

A 3-D, unsteady, two-phase flow model using a pseudo-fluid formulation has been developed at Purdue University under an ARL grant for the analysis of the unsteady growth and collapse of cavitation in a high-pressure, high-velocity flow. The new treatment is able to treat arbitrary void fractions from

pure liquid to pure vapor. It considers both pressure and inertia (hydrodynamic nonequilibrium) effects. Predictions have been compared against experimental measurements of cavitation in 2-D flow and have been shown to accurately predict the onset and extent of cavitation phenomena.

Impact: The ability to analyze these flows will lead to the re-design of injectors with improved materials for improved reliability in retrofitting existing engines. Optimization of high-performance diesel engines with higher injection pressures will be facilitated by the improved cavitation analysis capability. Injectors will be designed for improved wear and for spray quality more closely matched to engine needs.

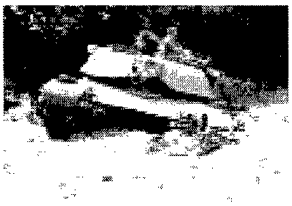


Research in Support of Off-Road Mobility

The Army requires real-time assessment of trafficability for rapid deployment and realistic vehicle-soil interaction models for training, mission planning, and vehicle analysis and design. Heavy tanks and armor vehicles must be mobile in mud or sand; thus requiring well-designed mobility vehicles to have well-designed tracks/wheels for various soil/ground conditions. However, properties of even the most commonly encountered clay soils are not well understood. Updated local, linear poroelastic models have been used since the 1940s.

In an ARL research program at Purdue University, first principles constitutive theory has been developed to change this situation. The model considered in this program includes interparticle forces of van der Waals (attractive), electrostatic (repulsive), and hydration (repulsive), and uses a multiscales approach for nonhomogeneities. An analytical framework has been developed for coupled-solvent and heat-transport equations, considering deformation coupled with fluid and energy transport, hysteresis, plasticity, salts, swelling, drying, crust formation, etc. Three spatial scales and one time scale are used: microscale or clay particles with local fluid, the meso-scale or the homogenized swelling particles with solvent and vapor, and, macroscale or saturated, homogenized particles, bulk liquid and vapor solvent. The mathematical analysis has resulted in two constitutive theories for small deformations, one time scale for dry soil and a multitime scale for moist soils. These theories incorporate (1) entropy inequality, linearization around equilibrium, (2) momentum balances allowing flow due to external stresses, gradients of volume fraction, pressure and temperature, (3) upscaling from meso to macro via matched asymptotics, and, (4) modified Green's function used to reduce dual porosity to single porosity with memory (or, a rigorous derivation of creep phenomena due to delayed intraparticle drainage).

Impact: This enhanced model for soil/sands has been incorporated in the Army vehicle design tool system CAMM (Condensed Army Modeling System) and will help with the design and performance of combat vehicles.



Research in Support of Flight

The Army After Next (AAN) will not materialize without the continued improvement in performance of helicopters. The flight characteristics of these support and attack vehicles are limited, in part, by the vortex shed by their rotor blades. In the hovering mode, such vortices can degrade overall performance and, through their interaction with the rotors in forward flight, these hydrodynamic flow fields generate severe vibrations.

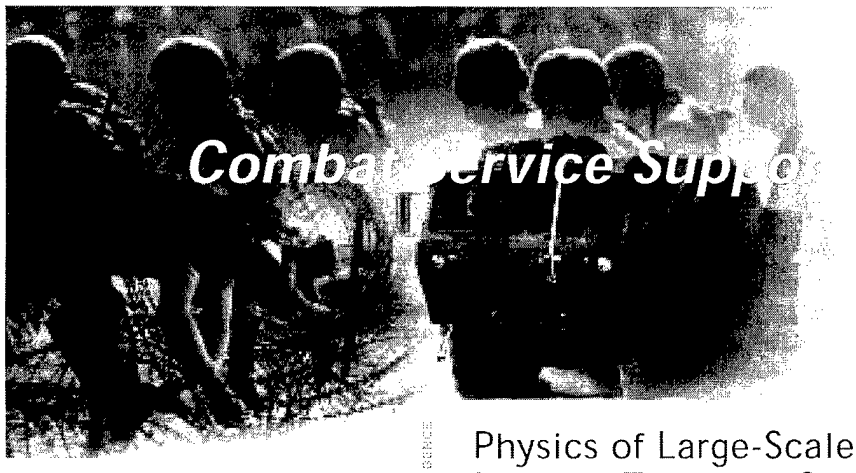
COMBAT SERVICE SUPPORT

SURVIVABILITY • LETHALITY • HUMAN FACTORS • MODEL, SIMULATION & SMART/C4ISR • MOBILITY • COMBAT SERVICE SUPPORT • SENSORS • COMMAND, CONTROL, COMMUNICATION, COMPUTER & INTELLIGENCE

An ARL research effort in mathematics with Harvard University and the University of Illinois in Chicago has obtained solutions to the equations governing such phenomena and provided a breakthrough in their understanding.

Researchers have constructed the first analytic solution to a nonlinear partial differential equation used to model turbulent fluid flow. The methods used include the generalized nonlinear filtering methodology, the Lie algebra approach, differential geometry, and solutions to (stochastic) nonlinear partial differential equations, including the Duncan-Mortensen-Zakai and Komogorov equations.

Impact: These mathematical results are laying the groundwork for the development of a new generation of hydrodynamic simulators of helicopter blade flow fields. Thus, the helicopter of the future may be reliably simulated in the computer, thereby reducing the need for tunnel testing and saving millions of dollars and years of time.



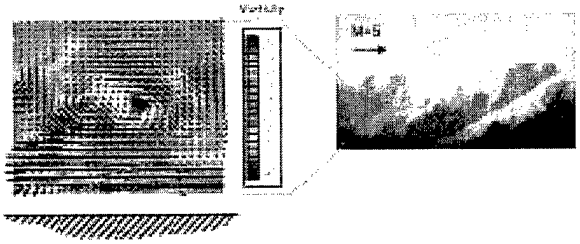
Physics of Large-Scale Unsteadiness of Shock-Induced Turbulent Separation

The unsteadiness associated with shock-induced turbulent boundary layer separation generates high-amplitude fluctuating loads that can lead to aerostructure failure. Shock-induced separation occurs on missile boat-tails, rotor blades, and around missile fins. Previous work has shown that the separation bubble, which undergoes a low-frequency contraction and expansion, drives the shock motion. Superimposed on this low-frequency motion is a high-frequency and smaller amplitude jitter. While the jitter is caused by the passage of turbulent structures originating in the upstream turbulent boundary layer, the source of the low-frequency high-amplitude motion has been unknown.

Researchers at the University of Texas at Austin have been investigating this phenomenon under ARL support. The first step of the investigation involved the extension of particle imaging velocimetry (PIV) to the harsh environment of supersonic turbulent boundary layers. PIV is a relatively new nonintrusive measurement technique that allows the simultaneous measurement of complete 2-D instantaneous velocity fields.

The next step was to use ensemble averaged conditional profiles of the streamwise velocity fluctuations, obtained using PIV, to study the flowfield. About 6,000 2-D velocity fluctuation fields were used to form the conditional average, which was sampled based on shock motion. Unequivocal correlation was found between fluctuations in the upstream boundary layer and the subsequent shock motion. Interestingly, only fluctuations very near the wall are the cause of the resulting shock motion.

Impact: The phenomenological knowledge about this low-frequency motion should enable the development of reliable, robust simulation tools (and ultimately design codes) capable of predicting the complex, 3-D, unsteady turbulent flowfields important to critical Army technologies, as well as the development of strategies (active flow control, innovative geometric arrangements) that mitigate the unfavorable effects of these flow



Fatigue-Life Methodology for Tapered Composite Flexbeam Laminates

ARL has been studying the viability of a method for determining the fatigue life of composite rotor hub flexbeam laminates using delamination fatigue characterization data and a geometric nonlinear finite element (FE) analysis. In this research, one-sixth size S2/E7T1 glass-epoxy nonlinear tapered flexbeam laminates with internal ply-drops were tested in a hydraulic load frame. Combined axial-tension and transverse cyclic bending loading were applied to simulate realistic flexbeam loading. Under this combined loading, delamination damage first occurred at the area around the tip of the outermost ply-drop group and grew stably in both directions along the length of the flexbeam. Under continued loading, unstable delamination occurred by complete delamination along the length of the specimen. A 2-D plane strain finite-element model of the flexbeam was developed that closely approximated the flexbeam geometry, boundary conditions, and loading. The model was analyzed using a geometrically nonlinear FE code. The global responses of the model and test specimens agreed well in terms of the transverse flexbeam tip-displacement and flapping angle under the combined loading. Delaminations were simulated in the model by releasing multipoint constraints (MPC) at the interfaces where delaminations were observed to occur in the specimens.

The FE model was used with the virtual crack closure technique (VCCT) to calculate strain energy release rates (G) for delaminations starting at the tip of the outer ply-drop group and growing toward the thick or thin regions of the flexbeam, as was observed in the flexbeam specimens. Material characterization data from cyclic double cantilevered beam tests were then used with the peak calculated G values to generate a curve to predict fatigue failure by unstable delamination as a function of the number of loading cycles. The calculated fatigue lives compared well with the test data.

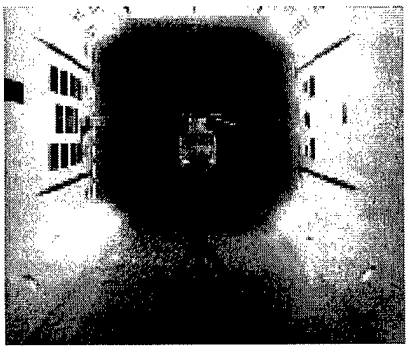
Impact: Calculated G values from simple FE analyses can be used with material characterization data to determine the fatigue life of composite rotor hub flexbeam laminates.

Active Twist Rotor Concept for Rotorcraft Vibration Control

Technical effort objectives (TEOs) for research in rotorcraft have been established by the Department of Defense. These TEOs include a 60% reduction in vibratory loads, a 24% increase in maximum blade loading by 2010, and several more. ARL is a partner with AMCOM in achieving these goals and objectives. At ARL, we have envisioned a revolutionary concept in collaboration with our partners at MIT that includes embedding piezoelectric fiber composite (PFC) laminates into the rotor blade spar. Using these PFC laminates and actively twisting the blade cyclically with the rotor azimuth, the local blade angle of attack can be altered to minimize the impact of local dynamic stall on the retreating side of the rotor disk; thus reducing rotor system vibratory loads. This PFC rotor system concept is basic research to develop the structure/smart-material coupling technology in a rotorcraft environment to transition the *smart material* development at MIT under ARL funding in the early 1990s.

Over the past three years, two complex analytical methods have been developed or modified to address the potential contribution of these fiber composite laminates to vibratory load reduction. Using these codes, a helicopter rotor blade has been designed and constructed with these fiber composite laminates embedded in the spar. Experimental testing of the Active Twist Rotor (ATR) prototype blade took place in FY99. The ATR blade was mounted on the Aeroelastic Rotor Experimental System (ARES) helicopter testbed with three nonactive blades identical in fixed twist and planform as the ATR prototype blade. Preliminary analyses of the results indicate that the design goals for twist actuation at the frequencies of interest have been achieved. A four-blade rotor system incorporating this ATR concept is now under construction for evaluation in late FY00.

Impact: By achieving the goals in the Rotor Wing Vehicle program for vibratory load reduction, the Army will have the technology to develop advanced rotor systems that are less costly to maintain and that have an improved environment for the pilot and passengers. The technology of the ATR will lead to a no swashplate rotor concept for the future, where the primary control of the rotorcraft is done with blade-morphing. Even greater levels of maintenance reduction will be possible by removing the fixed-to-rotating system control hardware.

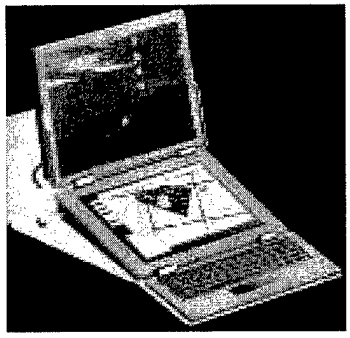


COMMAND, CONTROL, COMMUNICATION,COMPUTERS & INTELLIGENCE

Cellular Frequency-Hopping Code-Division Multiple Access Systems

In the 2010 timeframe, combat planning and execution are envisaged to be much faster than they are in the 1990s. Integrated C⁴I systems will be built to exchange data and work collaboratively with a view to help military forces prevail against adversaries by operating in a rapid, coherent, and coordinated fashion. As DoD emphasizes C⁴I systems and the tactical battlefield relies on wireless communications during that timeframe, cellular networks receive greater prominence.

Compared with other existing technology alternatives, code-division multiple access (CDMA) is advantageous for cellular networks because it eliminates the need for frequency and time slot coordination among cells, allows complete frequency reuse in all cells, and can fully exploit intermittent voice signals and sectorization. The frequency hopping CDMA has the advantage over the direct sequence CDMA in that it can be implemented over a much larger frequency band than is possible with the latter. Also FH CDMA provides resistance to multiple-access interference.

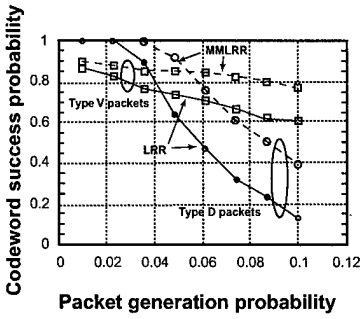


ARL research work is investigating the effect of hopping parameters, such as the duration of a hop, dwell time, and switching time on spectral splatter. Propagation path loss models and simulations are under development.

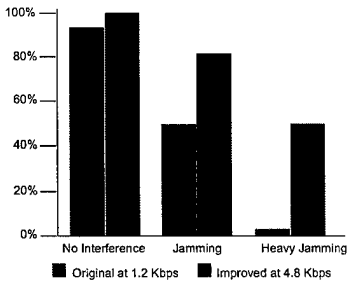
Impact: Our research results will allow designers to achieve a desired network capacity by choosing a sufficiently large number of frequency channels. The design and deployment of CDMA networks offer the advantage of a substantial reduction of system complexity and overhead cost and facilitates geolocation.

Multimedia Routing in Mobile Wireless Networks

Future Army operations are characterized by increased use of digital information products, more mobility, and a smaller communication spectrum. Mobile wireless communication networks are needed to provide multimedia transmission capability, greater capacity, and more reliable transmission. Research sponsored by ARL at Clemson University and TechnoScience, Inc., has resulted in the application of forward error correction (FEC) coding to improve the percentage of successful packet transmissions in a spread spectrum, frequency hop, packet radio network. The improvement achieved increases dramatically with the degree of interference or jamming as shown in the figure at lower left. This research result has been incorporated in the SINCGARS SIP (SINCGARS Improvement Program) by ITT. A technique called least resistance routing (LRR) uses the number of errors and erasures in the FEC code to determine a resistance value for each link in a network. This resistance is a measure of the quality of the link and the number errors that may occur. Packets are routed and forwarded over the multihop wireless links that have the least total resistance in order to minimize the delay and errors and increase the effective throughput of the network.



The LRR has also been extended to multimedia LRR (MMLRR) where packets are identified as data packets (type D), which are error sensitive but not delay sensitive and voice/video packets (type V), which are delay sensitive but tolerate some errors. MMLRR routes type V packets over routes of least delay measured by the number of packets in the transmission queues and transmits type D packets over routes with the least resistance. The figure at upper left shows a significant increase in codeword success probability for multimedia packets when MMLRR is used. MMLRR is being incorporated in the DARPA GloMo program and an Air Force SBIR program.



Impact: The use of FEC, LRR, and MMLRR has resulted in significantly improved throughput efficiency and capacity of bandwidth-limited mobile wireless networks on the battlefield for the Army. The research provides greater capacity to transmit the increasing quantity of information required in the digitization of the Army.

Rapid and Affordable Generation of Terrain and Detailed Urban Feature Data

Researchers at Purdue University, the University of Southern California, and Marconi Integrated Systems, Inc., are seeking new approaches to the generation of terrain and detailed urban features for 3-D databases. The overall objective of this project is to undertake the basic research necessary to develop new algorithms and tools for the generation of terrain and urban data needed to support Army requirements in battlefield visualization in a spatially accurate, consistent, and timely manner. The research completed to date has greatly improved the photogrammetric and image understanding approaches to the generation of detailed 3-D terrain and surface feature data, as well as the construction and management of such databases in a timely and affordable manner. Dramatic improvements in registration accuracy have permitted data fusion between frame imagery and hyperspectral thematic maps at a new level. Previously published results for similar data yielded 5- to 10-m (2 to 4 pixel) accuracy, whereas the new techniques have consistently yielded results in the 1- to 2-m (0.5 to 1 pixel) range. New methods have been developed and demonstrated for automatic cultural feature extraction using multiple image sources. These methods have resulted in much improved urban feature detection rates with much reduced false-alarm rates, and they have yielded new capabilities to attribute to the geometric models. Novel techniques for use of Bayesian reasoning methods have been developed to combine uncertain evidence from multiple sources. Novel methods also have been developed that address the extraction of urban road grids. Virtual reality visualization environments have been extended to allow viewing of the multisensor derived 3-D models as well as mensuration, model editing, and verification.

Impact: This research program, which is being done in collaboration with the U.S. Army Corps of Engineers' Engineer Research and Development Center to ensure rapid technology transfer, will enhance the battlefield situational awareness at all levels by providing new and enhanced capabilities for the rapid generation and integration of terrain data from remote sensing imagery of different types and for 3-D scene visualization. Additionally, this research will contribute to improved capabilities for training and mission rehearsal in the virtual environment.

Optical Characterization of Biological Aerosols

DoD's increased attention to the possibility of biological warfare and terrorism is reflected in the significant boost in its funding for research and defensive measures. Although thousands of biological agents are capable of causing human infection and could be considered a potential biological weapon, only a few pose serious threats. Those that are of most concern are particularly deadly when dispersed as an aerosol.

ARL researchers have formed a team with university and other DoD collaborators to develop methods for the rapid detection of potential biological warfare agent aerosols. This team has been developing a means of detecting and characterizing biological aerosols using optical techniques (laser-induced fluorescence and two-dimensional angular optical scattering). Working with collaborators at Yale University, ERDEC, the Naval Research Laboratory, and Oak Ridge Laboratory, the team has coupled theoretical and experimental investigations to invent and improve the capability of optical detection methods to distinguish biological aerosols from the natural background aerosol, and to partially classify bio-aerosol particles. Such a capability would serve as an *alarm* to turn on antibody-based or DNA probe bio-agent identifiers. This capability is vital if we are to mitigate the dangers posed by the use of biological agents dispersed on the battlefield or over civilian population centers. Most recently, this team and its collaborators have demonstrated the capability of rapidly measuring the fluorescent spectra of individual micrometer-size (capable of being inhaled) bio-aerosols illuminated by a pulsed, single-shot UV laser. They have demonstrated the power of using spectra for differentiating biological aerosols from nonbiological aerosols and for classifying biological aerosol particles.

Impact: The fluorescence-based technique pioneered by this team has been used to develop a commercial, fieldable bio-aerosol sensor. About 50 of these sensors are being purchased by the Army for the Biological Integrated Detection System (BIDS).

Signal Processing for Frequency-Hopping Networks

DoD is planning to rely more than ever on the use of high-technology C4I systems to leverage its military assets. In the 2010 timeframe, combat planning and execution are envisaged to be much faster than they are in the 1990s. Integrated C4I systems will be built to exchange data and work collaboratively with a view to help military forces prevail against adversaries by operating in a rapid, coherent, and coordinated fashion.

As the United States and its allies emphasize C4I systems, their adversaries will be preparing to launch an information offensive with the aim of compromising our information and to deny service to our forces and allies. Fast frequency-hopping (FH) networks provide robustness to jamming and interference. Advanced modulation approaches increase bandwidth efficiency, given the pressures on military spectrum allocation. ARL is conducting basic research in these areas to provide the Army with effective bandwidth usage and offer a higher degree of protection from enemy attacks.

At carrier frequencies above 2 to 3 GHz, the channel coherence time is too short or, in other words, the fading is too rapid to effect useful power control. A focus on frequency hopping is appropriate for military systems, since long codes are needed in the military setting. The hopping rate impacts all the receiver signal processing. Faster rates demand more accurate synchronization techniques for coherent demodulation, but also lessen the threat of follow-on jammers.

Impact: ARL research work will result in novel protocols that are especially suited for mobile tactical communication networks. With the digital signal processing techniques resulting from our work, the Army will be able to build and field communication systems that cater to the needs of the information intensive Army of 2010 and beyond.

Image Steganography and Data Hiding

DoD's plans for the 2010 timeframe include greater use of high-technology C4I systems to leverage its combat assets. Combat planning and execution seek large quantities of signal, image, and video information—a truly multimedia revolution in information exploitation to achieve information superiority.

The rapid development of commercial communications technologies offers opportunities and challenges to the military operators. Over the next few decades, we will see cheaper communication devices and systems, but these will come with the risk of increased *sniffing* of information by adversaries. Steganography is the ancient practice of surreptitious communications, and it may possibly be applied again.

However, new methods are needed for hidden communications that exploit the prevalence of multimedia data on the battlefield. In addition, next-generation communications networks will require covert modulation techniques for operation in a hostile environment and to maintain visual quality of the imagery embedded in large quantities of information.

Our research work will explore alternatives and provide a method to hide information within imagery for hidden communication, in-band captioning, and image tamper proofing. We also explore new methods of low probability of intercept and low probability of detect (LPI/LPD) communication. We will deliver an SSIS system consisting of encoder/decoder for integration within the ARL telecommunications testbed.

Impact: With the methods coming from the ARL research work, the Army will be able to transmit information intensive images around the battlefield and between the strategic levels and the battlefield. In seemingly innocuous image and video information, the military operators can hide vital battlefield information and transmit it to strategic destinations. At the same time, the hidden information can be guaranteed from compromise. Or where a high-level of guarantee cannot be given, a probability of detection and whether detection has occurred can be determined. Such information and the metainformation (information about the security of information) will be invaluable to the military operators.

Noncooperative Signal Processing

One aspect of the DoD's reliance on C4I systems to leverage its military assets involves the development of intelligence information in its concept of a sensor-to-shooter closed loop. Passive detection, estimation, and surveillance of numerous battlefield emitters and sources are fundamental to the Army's mission of recognizing and identifying targets to be handed off to shooters. Blind signal processing presents significant challenges beyond conventional communications, radar, and aeroacoustics techniques. ARL research consists of analysis, modeling, and development of digital signal processing (DSP) for passive detection, estimation, classification, and tracking of the signal sources.

Our research is focused on the classification of digital communication signals, investigation of the fundamental limits on detection, estimation of modulated signals, blind co-channel source separation, and detection and estimation of ultra-wideband sources.

We plan to develop low complexity modulation classification algorithms and genetic algorithms, analysis of blind source separation DSP, and detection schemes for ultra-wideband impulse radar/radios. We will also model distributed sensor arrays.

Impact: Signal processing and classification of emitting devices is of great value to the Army commanders in the field. Our methods, techniques, and algorithms will be able to detect, and classify emitters. With such information, field commanders can make expeditious decisions on the fate of the emitters.

Uniplanar Compact Photonic Bandgap Research

In the present state-of-the-art high-frequency integrated circuits, it is very difficult to obtain high frequency circuits with low insertion loss, sharp cutoff of the filters selecting the frequency band, and efficient antennas, to just name a few examples. Such deficiencies in the passive circuit components also place tremendous burden on active devices (such as transistor amplifiers). To rectify this situation, a revolutionary new structure, the uniplanar compact photonic bandgap (UC-PBG), has been investigated at the University of California at Los Angeles, to determine its potential for impacting many of the passive and active components utilized in low-power wireless communication systems. The UC-PBG structure is essentially a two-dimensional lattice that is etched on the ground plane of conventional microwave integrated circuit components. Here, traditional photolithographic process steps are used to make a new compact structure that is completely compatible with existing components and fabrication procedures.

When compared with conventional microstrip or coplanar waveguide (CPW) structures on solid ground plane, the UC-PBG offers several unique properties for the propagation and reflection of electromagnetic waves, including low insertion loss, slow-wave effect, wide stopband, and easy realization of a perfect magnetic impedance surface.

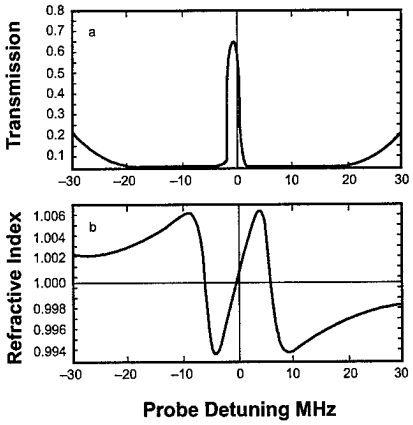
Impact: Successful demonstrations have shown the great potential of this new UC-PBG structure, even though we are still at the early stage of its development and need more in-depth investigation to further expand its range of applications. It is recognized widely that planar circuit technology will have a very difficult time matching the performance of the bulky metallic waveguide systems in terms of insertion loss or radiation efficiency. However, this research has made a very important first step toward realizing a high performance planer technology that can effectively take advantage of reduced hardware size and weight, easier integration with solid-state devices, low power consumption, and conformal implementation on moving platforms. Clearly, this research has a strong potential to impact the Army's mid- and long-term capability in wireless communications.

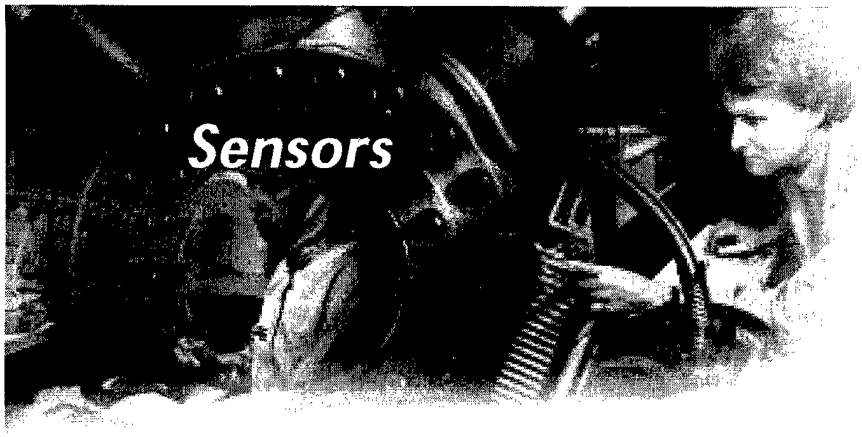
Enhanced Nonlinear Optics in Cooled Atoms

With ARL support, collaborative researchers from Stanford University and the Rowland Institute have demonstrated a technique for greatly enhanced nonlinear optical effects. They used electromagnetically induced transparency to propagate a pulse of light through an otherwise opaque cloud of sodium atoms that had been evaporatively cooled to nK temperatures. The speed of propagation of the light pulse was slowed by more than a factor of ten million, and the nonlinear index of the medium was greatly enhanced. These results open possibilities for both fundamental interactions between light and matter and for new types of optical devices that may operate at extremely low optical energies and would be of great practical importance to the Army.

Electromagnetically induced transparency for a laser pulse is obtained by propagating a second laser beam, called a coupling laser, at a right angle to the pulse. With the correct choice of intensity, polarization, and frequency, a quantum interference is established that results in a narrow transmission window for the laser pulse in the cold sodium cloud. The resulting steep refractive index profile produces an extremely slow optical group velocity for the light pulse. The slow group velocities are closely tied to exceedingly large optical nonlinearities. As the coupling laser frequency is reduced, the dispersion is increased and the nonlinear refractive index becomes nearly a million times greater than that measured in cold cesium atoms. In addition to producing extraordinarily large nonlinearities, the technique is also extremely energy efficient. These effects can be accessed with a laser intensity corresponding to only one photon in an area equal to an atomic cross section.

Impact: The large nonlinearities and low switching energies open up a number of novel Army applications, ranging from optical delay lines for phased-array radar systems, to optical computing for computationally intensive tasks such as automatic target recognition.





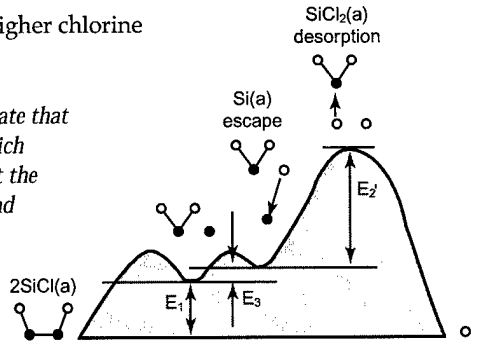
Silicon-Vacancy Model for Dry Etching of Silicon

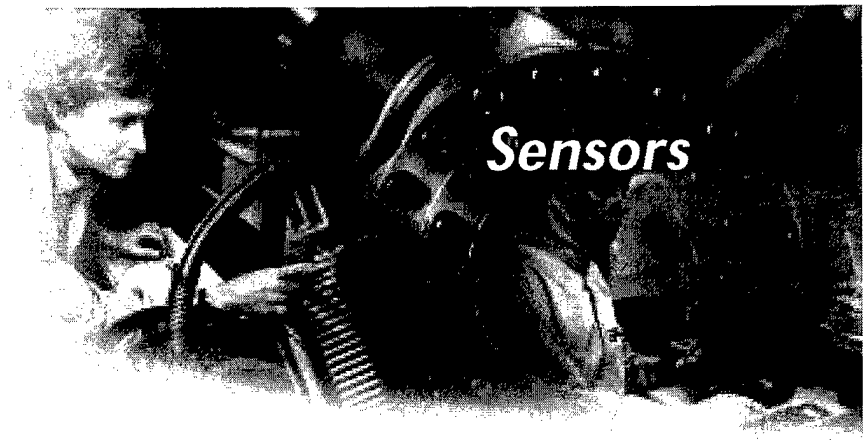
The chemical etching of silicon is an essential part of the processing of all Si microchips and microelectromechanical systems (MEMS). Researchers at the University of Minnesota have finally established the step-by-step sequence of atomic events that transpire during the dry etching of silicon by halogen gasses. Surprisingly, they found that the process of thermally activated etching differs significantly from generally accepted beliefs. The conventional understanding involves the reaction $2SiCl \rightarrow SiCl_2 + Si$ followed by the thermal desorption of $SiCl_2$. In the potential energy diagram shown here, this would imply direct desorption from the first well. However, the barrier for desorption is so large and the barrier against the reverse reaction is so small that there is very little chance for desorption to occur.

Guided by calculations, however, the Minnesota group has determined that the rate of desorption can be greatly enhanced if the reverse reaction can be eliminated, for example, by vacancy creation adjacent to the $SiCl_2$ species. This introduces a second well in the energy surface, as shown. Vacancy creation is depicted by *Si(a) escape* and it involves the transfer of the Si atom Si(a) onto a terrace. The lifetime of the $SiCl_2$ species is thereby increased since its decay pathway is eliminated.

To demonstrate that this new model was correct, they measured Si etch rate as a function of surface coverage. This was important because the escape of the Si atom onto the terrace is blocked as the surface becomes saturated with Cl. In this new model, the etch rate should reach a maximum at intermediate coverage and *more would not necessarily be better.* This was just what they found when they made atomic-scale STM images of the Si surface before and after etching with successively higher chlorine concentrations.

Impact: Results from the model demonstrate that the surface is not a passive backdrop against which desorption occurs. Instead, the model shows that the surface plays a pivotal role via defect creation and defect-assisted desorption.



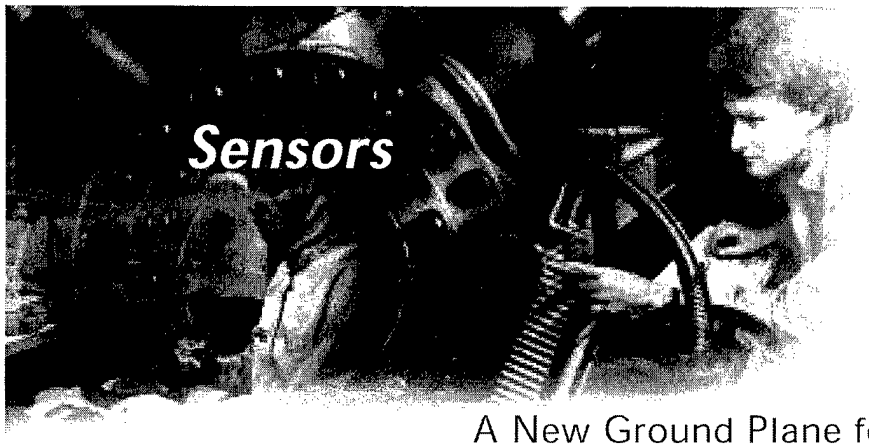


Growth of Oxide Films Exhibiting a Self-Similar, Hierarchical Structure

Using combinations of emulsion processing and micromold patterning of inorganic/organic mesophases, researchers at the University of California, Santa Barbara, (UCSB) have been able to create hierarchical order in mesoporous structures spanning several length scales. The significance of these advances is that they allow, for the first time, the design and preparation of multifunctional composite structures with well-defined structural order extending from nanometer to centimeter length scales. This is analogous to the control of $CaCO_3$ biomineralization by marine mollusks and SiO_2 organization exercised by diatoms and siliceous sponges. The mechanisms that the UCSB group used to achieve this synthetic structure bear a fundamental relationship to those that were discovered in biological systems.

In one demonstration of this principle, a mesoporous oxide structure displayed controllable order over two distinct length scales. Block-copolymer microemulsion droplets with a narrow size distribution were used as templates to produce a highly ordered, three-dimensional hexagonal array of 12-nm pores. Simultaneously, a pattern on the 12-μm scale was imposed by using kinetically frustrated macrophase separation to form a self-organized structure of larger droplets around which the microemulsion could form.

Impact: This principle can be used to provide controlled patterning on multiple macroscopic length scale to produce virtually any mesoporous, hierarchical structure. Potential applications for these types of materials include filters, catalyst supports, and integrated microelectronics.

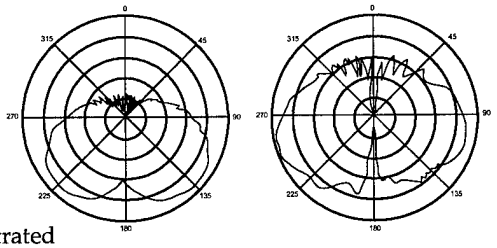


A New Ground Plane for Flush-Mounted Antennas

A new radio frequency (rf) ground plane has been developed by the ARL-sponsored Multidisciplinary University Research Initiative Center at UCLA that promises to revolutionize antenna design for radar and portable wireless communications systems. This type of ground plane is a common feature of most rf and microwave antennas. It consists of a conductive surface lying below the antenna that directs most of the radiation into one hemisphere. Frequently, a ground plane is present by necessity rather than intent, as with metal-skinned aircraft. However, purely metallic ground planes will short a flush-mounted antenna or will generate unwanted side lobes by destructively reflecting radiation out of phase with the antenna radiation. The UCLA investigators employed photonic bandgap concepts to invent a new kind of metallic high-impedance ground plane (HIGP) structure. The HIGP structure exhibits the following two unusual electromagnetic properties that overcome the limitations of metallic ground planes:

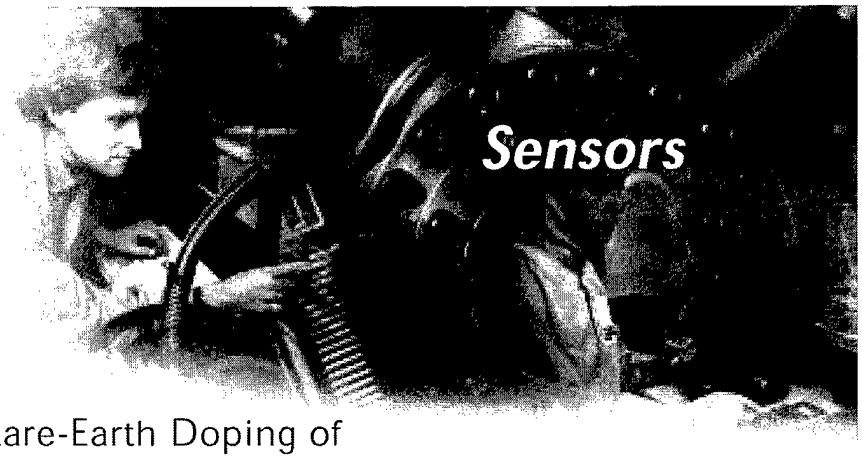
(1) It does not allow rf electric currents to propagate along the surface; that is, it is an rf open circuit, while being a dc short circuit.

(2) It reflects electromagnetic radiation in phase rather than out of phase as a normal metal surface does.



This new ground plane, also known as a perfect magnetic conductor, was demonstrated using printed circuit board technology. The surface serves as a 2-D metallic photonic crystal, eliminating rf surface currents. As a result, radiating elements can be located very near the surface without being shorted by the ground plane. The rf surface current suppression can permit antennas that are more efficient, and reduce coupling between elements in arrays and interference between nearby antennas on rotorcraft or other vehicles. The resulting antenna pattern is smoother than the corresponding antenna pattern for a metallic ground plane.

Impact: This new type of surface should find many uses, including ground planes for flush-mounted antennas, mutual isolation of multiple antennas within a single rf aperture, and other applications in Army aviation and wireless communications.

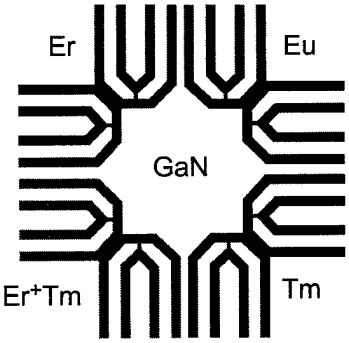


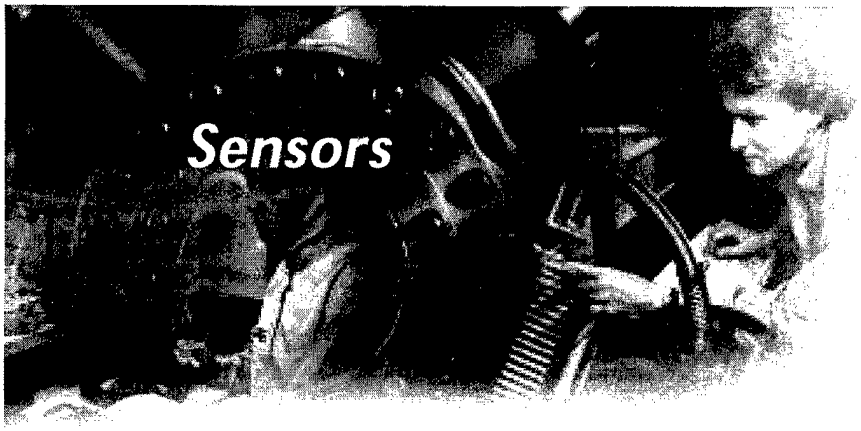
Schottky Diodes From Rare-Earth Doping of Gallium Nitride

Laser sources whose frequency (or wavelength) can jump with great agility over a range of values are expected to enable major advances in many military applications. To produce a wide wavelength range capability using conventional semiconductor laser approaches would require the integration of many different semiconductor materials or their alloys. At the University of Cincinnati, researchers are developing an alternative approach to producing lasers capable of frequency agility by utilizing a single host material doped with luminescent rare-earth species.

Visible and infrared rare-earth-activated light-emitting diodes (LED) have been obtained from Schottky barrier diodes consisting of indium tin oxide (ITO) contacts on a rare-earth-doped gallium nitride (GaN) layer grown on silicon. The GaN was grown by molecular beam epitaxy (MBE) on silicon substrates using solid sources for gallium, magnesium, rare-earth elements (erbium (Er), europium (Eu), and thallium (Tm)), and a plasma source for nitrogen. The figure shown was used on the cover of the September 1999 *Materials Research Symposium Bulletin* on photonic applications of rare-earth-doped materials. The image is a collage of GaN-LEDs doped with various rare earths to produce the red, green, and blue primary colors, as well as a mixed color (aqua) obtained by co-doping. The simultaneous emission from Tm, Er, and Eu indicates that the potential of the GaN:rare-earth approach can lead to a full color display, also the implementation of the frequency agile laser.

Impact: Laser sources whose frequency can jump with great agility over a wide range are expected to enable major advances in many military applications, such as greatly improved security in communication systems and improved accuracy and speed in the detection and identification of chemical and biological hazards. The development of frequency agile lasers will greatly benefit from the miniaturization, robustness, and low cost generally associated with semiconductor technology.





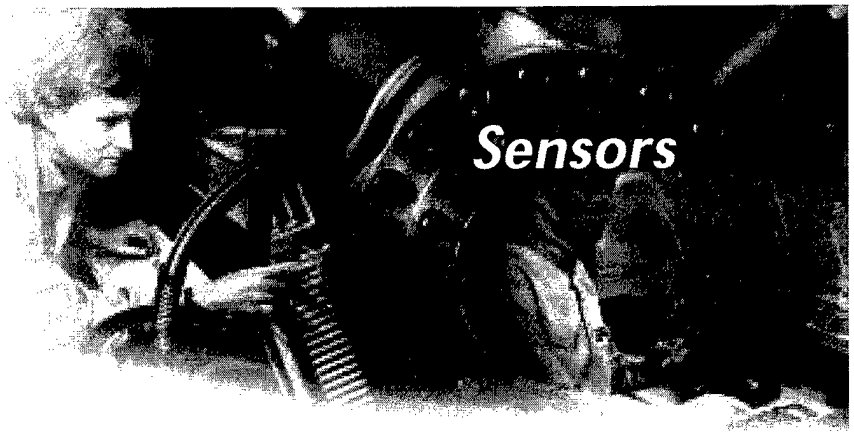
Acoustics Propagation and Technology

Acoustic technology has become important to modern Army applications for a number of reasons. Acoustic sensors are inexpensive due to modern digital signal processing and can thus be deployed in large numbers. Acoustic sensors can provide nonline-of-sight information and are relatively unimpeded by terrain, vegetation, and obscurants. Acoustic information can be fused with information from other sensors to provide a plus-up capability. ARL researchers have developed research projects that, when combined, provide the Army with an integrated acoustical sensing capability that provides real and practical breakthroughs in a critical technology. The approach they have taken provides an edge in an emerging technology.

The Atmospheric Acoustics Team develops state-of-the-art models for environmental effects on acoustic propagation, incorporating these models into battlefield decision aids. Recent research has emphasized the role of the atmosphere in determining the performance of arrays of acoustic sensors, since such arrays are a part of many new and planned systems. The team has developed a unique capability for predicting the performance of acoustic arrays operating in the atmosphere.

Last year, the Advanced Systems Concepts Division of the Space and Missile Defense Command approached ARL with a new concept for using acoustic sensor arrays to track low-flying cruise missiles that cannot be detected by conventional radar. Through collaboration with ARL researchers, it was determined that tracking missiles acoustically was certainly feasible, and suggested maximum distances at which missiles could be tracked were presented. New statistical methods to analyze the effects of source motion and finite propagation times on acoustic tracking were developed. These new methods were incorporated into the Acoustic Battlefield Aid (ABFA), and the modified program was used to determine the accuracy with which a missile can be tracked for different flight characteristics and atmospheric conditions.

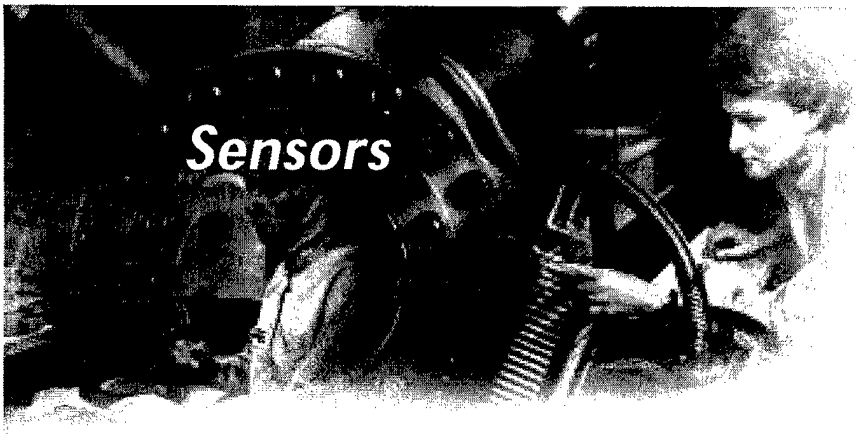
Impact: The evaluation of the cruise missile tracking concept was presented at the SARDA level, and played a role in the Army's decision to further pursue the concept. The team members addressed the performance characteristics of the wide area munition (WAM) in different environmental conditions and suggested enhancements to the system. Also, ABFA is being used to model the detectability of the Comanche helicopter and will be integrated into a combined acoustic/seismic battlefield decision aid that is intended to become the Army standard.



First Measurement of High Field Electron Saturation Velocity in Gallium Nitride

ARL has developed a novel optically detected time-of-flight technique that employs ultraviolet femtosecond pulses in monitoring small perturbations in the electroabsorption of gallium nitride (GaN) pin diodes due to charge transport. This technique has been used to perform the first measurement of the electron velocity at high electric fields in GaN. Theoretical calculations of electron velocity versus electric field characteristics had not been experimentally confirmed. The experimentally determined electron saturation velocity and velocity-field characteristic are in excellent agreement with the calculations of top researchers in this area.

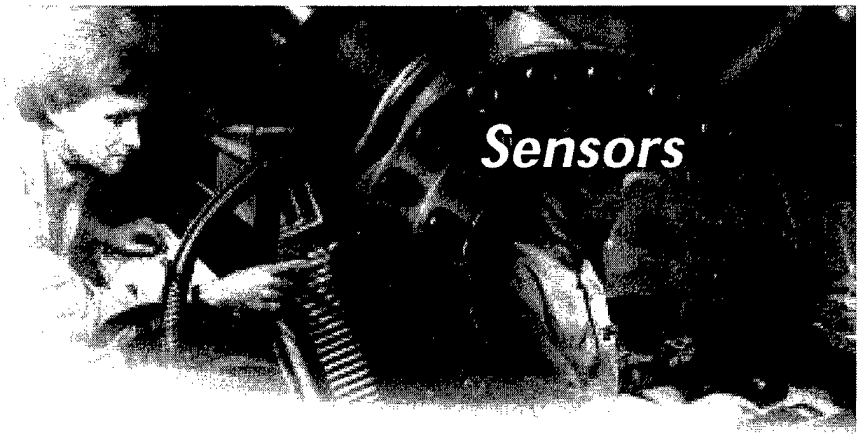
Impact: GaN possesses the wide bandgap and high breakdown voltage necessary for high-temperature and high-power Army electronics. The high saturation velocity in GaN also makes it an important candidate for ultra-high frequency, high-power devices crucial to next generation Army applications requiring lightweight, all-solid-state components. Current electronic measurements of device performance are limited to less than 40 GHz. The optically detected time-of-flight technique allows ARL to determine the ultimate speed of nanoscale GaN devices and provide critical evaluation of the technology for future Army systems.



Automated Material Classification for Hyperspectral Imagery

ARL has developed an automated algorithm for material classification with hyperspectral images. The algorithm labels every pixel in the image by material type, using the spectral signature of the pixel along with information from nearby pixels. The algorithm differs from existing algorithms in its use of adaptive coarse-to-fine spectral estimation of the spectral signature of each material class, which allows the algorithm to automatically and locally adjust to distortions of the spectral signature caused by increased attenuation; material anomalies; or spectrally selective atmospheric constituents such as smoke, dust, or gases. Most existing algorithms try to account for spectral signature distortion by maintaining large libraries of signatures or by applying a library of attenuation profiles interfaced to a smaller library of signatures. This research used a series of images produced by the AOTF (acousto-optical tunable filter) sensor that ARL has helped to develop.

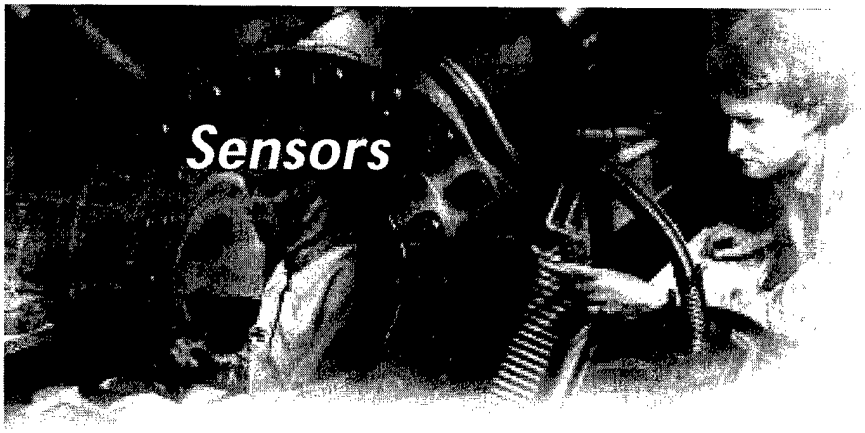
Impact: Hyperspectral imaging is an active area of research because it demonstrates potential for vast improvement in target detection over broadband imaging. As the use of hyperspectral imagers becomes ubiquitous on reconnaissance platforms, the amount of data to be processed will overwhelm an analyst. For that reason, the demand for automated algorithms to assist image analysts will increase rapidly. Algorithms such as the one described in this summary will be able to accurately locate objects that are made of different material than their background. This work will fall under an STO and a Center of Excellence being developed among ARL, the Topographic Engineering Center, the Night Vision and Electronic Sensors Directorate of CECOM, and the Space Missile Defense Command.



Pulsed-Laser Deposition of an Insulator for High-Temperature Electronics

The high-temperature dielectric properties of thin-film AlN that was placed on heavily doped *n*-type 6H and 4H-SiC substrates with pulsed-laser deposition (PLD) have been investigated from 25 to 450 °C. Very low leakage current densities (10^{-8} A/cm^2 at 25 °C and 10^{-3} A/cm^2 at 450 °C for a 1.7-MV/cm dielectric field) have been achieved. These leakage currents are orders of magnitude lower than values that have been previously reported for thin films of AlN even though the earlier studies reported I-V characteristics at significantly lower temperatures and fields. The 6H PLD AlN values for the 1.7-MV/cm dielectric field appear on the bottom left. The primary high-temperature leakage mechanism appears to be Schottky emission with zero-field barrier heights for 6H and 4H of 1.68 and 1.55 eV, respectively. This work was done in collaboration with the University of Maryland through the Microelectronics Research Cooperative Program (MRCP).

Impact: Robust high-temperature insulators will be required for wide bandgap (WBG) electric-drive circuitry to implement future Army electric-drive ground systems. Because high-temperature WBG electronics provide highly efficient switching of very high power and can be cooled with the available cooling fluid (engine oil at 90 to 125 °C), no additional vehicle cooling system is required. Current state-of-the-art Si electronics, in contrast, must be cooled by a large 65 °C cooling system. By avoiding the space and weight penalty of this additional cooling system, WBG electronics will allow future hybrid electric combat vehicles to have all the required capabilities (extended silent watch, stealth maneuvering, active protection, and the electric gun), along with reduced vehicle weight, improved range, and enhanced survivability.



Type-II Mid-IR Semiconductor Lasers

ARL scientists have demonstrated type-II interband cascade (IC) lasers emitting near 3.9 mm. Type-II IC lasers take advantage of the broken band-gap alignment in InAs/Ga(In)Sb heterostructures to reuse electrons for sequential photon emissions from successively connected active regions. The lasers exhibit exceedingly high differential quantum efficiencies and peak powers, and are able to operate at temperatures up to 217 K. Several devices operated at temperatures above 80 K exhibit a slope greater than 750 mW/A per facet, corresponding to a differential external quantum efficiency exceeding 460%. A peak optical output power exceeding 4 W/facet and peak power efficiency of ~7% were observed from a device at 80 K. The results indicated that these IC laser structures are much better when compared to the previous temperature and efficiency records.

Impact: Tactical infrared counter measures (IRCM) applications require mid-IR semiconductor lasers with high output powers and operating temperatures. The sources developed at ARL can provide the capability to counter present and future threats to rotary wing (and other) aircraft from air- and ground-launched missiles with imaging and nonimaging IR seekers. The ability to make an efficient diode laser that meets IRCM requirements could result in systems with significant advantages in terms of cost, weight, volume, reliability, and simplicity.

Applied Research

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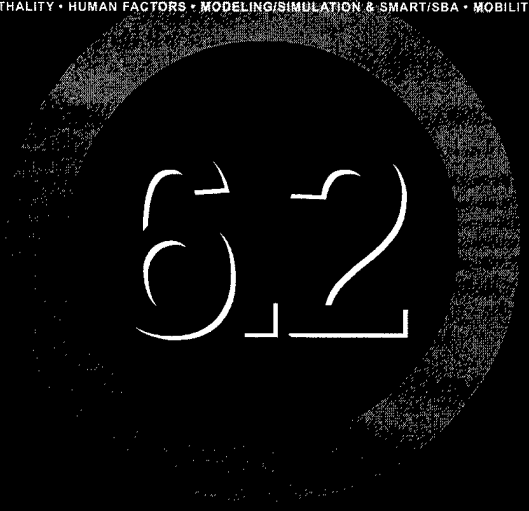

The Applied Research (6.2) program develops technology opportunities and evaluates their technical feasibility for increased warfighting capability.

Applied research includes all efforts directed toward the solution of specific military problems, short of major program demonstrations and development projects. At ARL, the applied research category includes the development of components, models, and new concepts through in-house and industry efforts. Individual research programs often enable a variety of new systems and support a number of identified needs. Since research programs may readily contribute to needs in several mission areas, ARL performs horizontal integration, or *cross-mission-area analyses,* to better understand 6.2 funding priorities.

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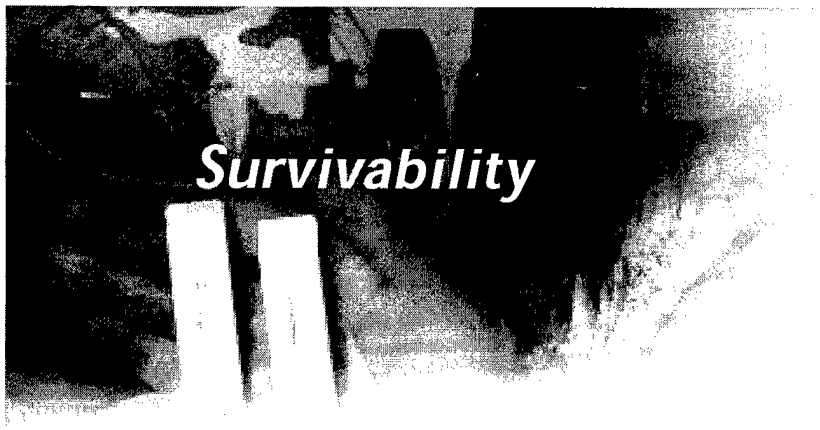
Armor Technology for Future Lightweight Ground Combat Vehicles

The TARDEC Future Light Vehicle Ballistic Protection Technology and Advanced Protection and Protection Design Technology Science and Technology Objectives are aimed at improving armor protection for future ground combat vehicles in the 18- to 40-ton range. ARL's armor research program is supporting the successful completion of these objectives by providing armor technologies for protection for lightweight vehicles against large-caliber

kinetic-energy penetrators, medium-caliber cannon threats, light and medium shaped-charge warheads, top-attack munitions, and antivehicle mines.

ARL has developed advanced capability in armor-penetration modeling that treats 3-D effects, material strength, and fracture mechanics. Full material descriptive 3-D penetration simulations have been performed with energetic and ductile materials. Simulations have suggested target design improvements from numerical results, reducing test costs and improving penetrator-target interaction diagnostics. Fracture modeling remains a challenging area, especially where fracture is pervasive rather than localized, as is the case with more brittle materials.

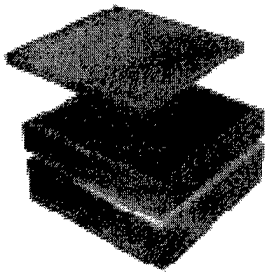
Impact: A frontal armor system is being developed capable of defeating all tank-gun launched threats at 65% of the weight of the current Abrams Main Battle Tank armor. Computational modeling, coupled with model-scale and full-scale experimentation of component technology, has demonstrated mass efficiencies suitable for an energetic smart armor system that can meet the objective.

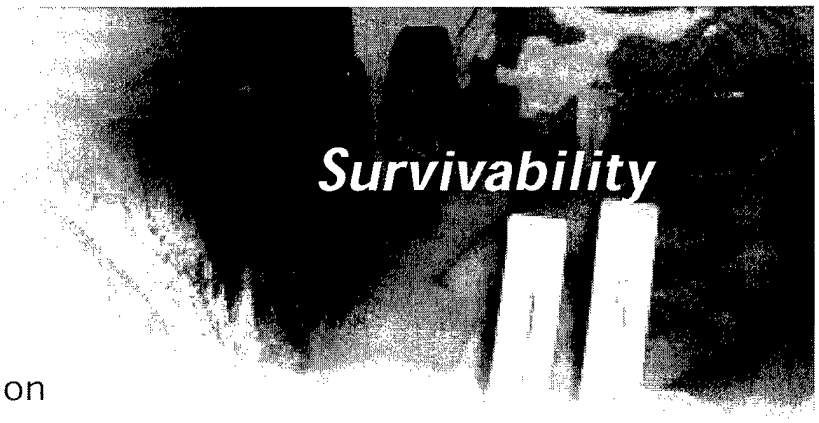


Ultralight Ballistically Resistant Materials

The U.S. armor community is engaged in an accelerated effort to develop armor designs that can defeat armor-piercing small-caliber threats at significantly reduced aerial weights. The individual soldier will need lighter weight, more robust, and integrated armor materials and systems to meet Army After Next requirements for enhancing combat personnel effectiveness and survivability in the face of a widening range of more lethal and countering threats. ARL is demonstrating a material system for improving ballistic performance of personnel armor, featuring a 40% weight reduction from that of the current system (5.4 vs. 9.0 lb/sq. ft) at equal or improved ballistic protection. Recent ballistic evaluations have led to the identification of two candidate systems composed of ceramic/composite laminate designs that will meet the above goals. Mechanical and dynamic experimentation of these material systems is being conducted.

Impact: The technology resulting from this research will be transitioned to the Soldier and Biological/Chemical Command (SBCCOM) for application in personnel armor system developments. Additionally, this research will be coordinated with ongoing DARPA initiatives for applying advanced technologies to improve individual soldier protection.

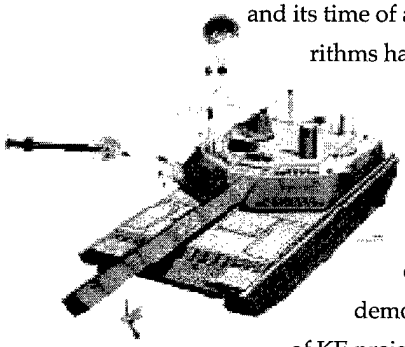




Counter-KE Active Protection

Active protection systems (APS) have the potential of providing survivability options for future ground combat vehicles to defeat emerging antiarmor threats at significantly reduced weights. ARL is supporting the TACOM Full-Spectrum Active Protection Program by exploring enabling technologies that can be applied to active protection systems to defeat the large-caliber kinetic-energy (KE) threats. The ARL Counter-KE APS Program is aimed at moving the engagement envelope for the defeat of tank-fired KE rounds beyond the outer skin of the vehicle. Consequently, relatively light structures can be used for protection instead of the usual heavy passive armors. This requires the development of technologies for threat tracking, countermunition engagement, and passive armor defeat of the residual KE threat.

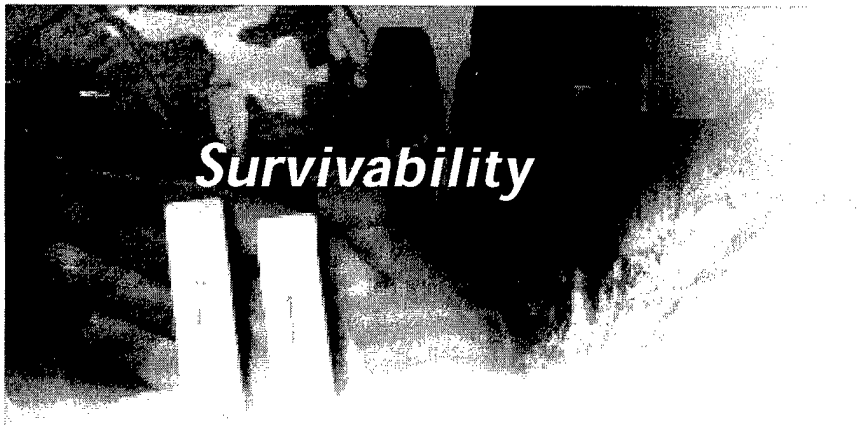
A passive infrared tracking sensor has been developed and demonstrated. The ARL-developed passive IR tracker successfully tracked a full-scale KE rod, and its time of arrival on *target* calculated in real time. Tracking algorithms have been improved and further experimentation is being conducted to demonstrate improved precision.



Electromagnetic, explosive, and blast/fragmenting warhead countermunition designs have been developed and demonstrated. Multiple successful launches of compact explosively launched multibar devices were demonstrated as stand-alone tests and in successful intercepts of KE projectiles. Experiments with improved blast/fragmenting warhead designs versus depleted uranium and tungsten penetrators have been conducted.

A 2-D model for system analysis based on sensor/countermunition/threat and vulnerability/lethality data has been developed. A quasistatic structural analysis model for investigating blast-wave/KE penetrator interaction phenomena has also been developed.

Impact: Passive armor concepts to complement APS have been researched. Multiple configurations of metals and ceramic/composite laminates have been evaluated for effectiveness against short fragments that simulate a residual KE rod intercepted by a countermunition, and a technology has been downselected for further tests.

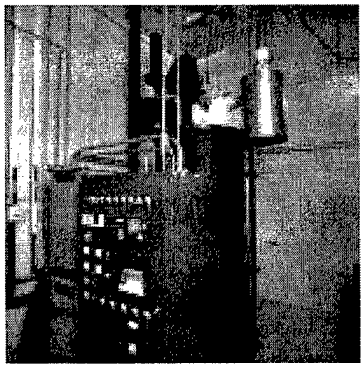


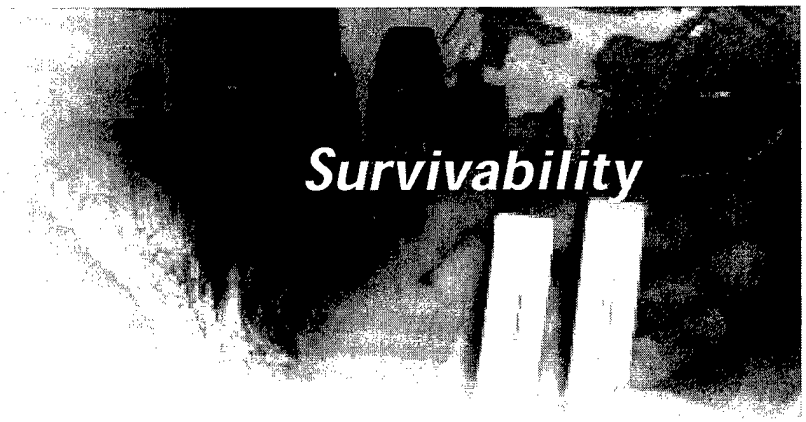
Lightweight Composite Integral Armor Technology

ARL made several contributions to advance the state of the art of multifunctional armor technology based on the application of polymer-matrix composites, ceramics, elastomers, and other materials.

A four-year Science and Technology Objective was initiated for low-cost composite armor processing. Short-term objectives include achieving significant increases in the ballistic resistance of multifunctional armor systems, developing new techniques for processing functionally graded composites, enhancing the coupling of fibers and matrix materials in composite systems, and evaluating emerging high-performance materials for Army applications. Efforts in FY99 concentrated on improving the integration of materials into multifunctional armors. Enhancements in ballistic resistance were made in armor modules through reinforcement and confinement using polymer-matrix composites. Candidate low-cost processing technologies were investigated through modeling and subscale experimentation. Characterization of the chemical, thermal, and mechanical properties of new, very high-modulus, high-strength fibers was also completed.

Impact: This multidisciplinary research effort will enable the development of lightweight, strategically deployable vehicle systems with advanced survivability to defeat antiarmor threats.





Nanomaterials for Advanced Survivability Technologies

The realization of future combat systems that meet requirements for enhanced mobility, deployability, lethality, and survivability will not be possible without the development and application of new materials with properties that surpass the current limits. The aggressive advance of smart materials, solid-state devices, and biomimetic technologies and the concurrent push toward miniaturization is driving the design of nanoscale structure and functionality into material systems.

ARL is pursuing advanced research in nanomaterials that are potentially applicable to lightweight structures, transparent armor systems, chemical/biological protection systems, and fire protection. The relationship between processing, nanostructure, and macroscopic properties of nanomaterials is being investigated.

Significant advances were made in nanomaterials for chemical/biological protection. A dendritic-polymer-based handheld assay was developed that has demonstrated reliable detection of the presence of a biological agent at extremely low concentrations when applied to point-detection systems that feature advanced critical reagents such as recombinant antibodies. Through the process of nanoencapsulation, enzyme-based nanocapsules and polymer-based nanoreactors were demonstrated to intercept and neutralize chemical and biological agents.

Impact: In a joint effort with SBCCOM, ARL has advanced the process of electrospinning these materials into fibers that can be applied to a variety of fabrics, including the fabric used for the current battle dress uniform. Nanoencapsulations, nanoreactors, and nanoemulsions have also been investigated for potential application in chemical/biological decontamination.

Robotics and Autonomous Platform Technologies

Major accomplishments were made in support of the Demo III Program—a four-year program aimed at developing technologies for integration on vehicle platforms and conducting field experiments of these platforms using Army and Marine Corps troops.

LETHALITY

SURVIVABILITY • LETHALITY • HUMAN FACTORS • MOBILITY/S MULATION & SMARTS/SA • MOBILITY • COMBAT SERVICE SUPPORT • SENSORS • COMMAND, CONTROL, COMMUNICATION, COMPUTER & INTELLIGENCE

Based on design and test validation of an engineering model of the Mobile Detection, Assessment, and Response System (MDARS) vehicle, a NATO Reference Mobility Model (NRMM) was generated and is providing the technical foundation for NRMM prediction of the Demo III Experimental Unmanned Vehicle (XUV). The assumptions of manned operation implicit in the model were investigated, and modifications were identified to accurately represent unmanned operations. These include replacing the human limitation on G-load with unmanned ground vehicle (UGV) limits, limiting the ride quality by vision sensors, and replacing driver prudence by deterministic terrain-dependent velocity algorithms based on chassis accelerations.

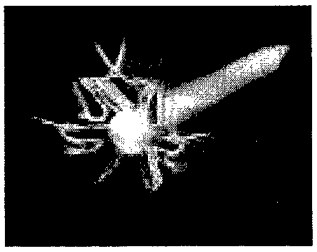
Robotic scout behaviors have been investigated based on the Demo III XUV. Requisite behaviors for scout and reconnaissance, surveillance, and target acquisition missions have been detailed to support the Demo III Battle Lab Warfighting Experiments (BLWE). Experimental data of UGV performance from the Demo III BLWE are being collected and will be used to verify and validate engineering models of the Demo III XUV.

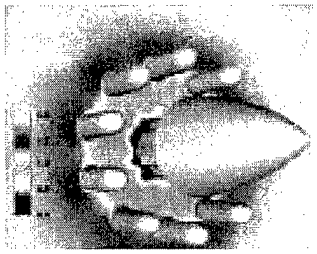
Impact: ARL continues to play a pivotal role in the development and demonstration of technologies that will enable the employment of UGVs in military applications.

Novel Lethal Mechanisms for Missile Applications

As part of the Target Destruct Science and Technology Objective, ARL conducted computational hydrocode simulations and experiments to identify and integrate missile components as part of the lethal mechanism and to quantify their contribution to lethality. The impact of different missile nose-cone materials and the effect of striking velocity of the nose cone on initiation of reactive armor were investigated. The potential of using a long-standoff warhead to defeat advanced explosive reactive armors is also being investigated. Experimental tests have demonstrated the feasibility of forming a hypervelocity, high-density, aerodynamically stable pellet through the early arrest of the jet-formation process. A terminal-ballistics trade analysis was initiated to evaluate various lethal mechanisms for a compact missile design, based on parametric missile model results that provide velocity versus range data as a function of geometry and mass distribution.

Impact: ARL is investigating novel lethal mechanisms that will enable reductions in the size and weight of missiles while maintaining or improving lethality.





Multidisciplinary Design for Competent Precision-Fire Technology

This multidisciplinary effort features high-fidelity computational modeling and experimental testing to investigate the integration of advanced components and design methodologies in competent precision-fire munitions. Algorithms were developed for coupling computational fluid dynamics and structural dynamics of advanced munition component designs.

Structural modeling and experimental shock testing were conducted to investigate on-board guidance, navigation, and control components. Commercially developed components being evaluated include canards, jets, thruster modules, angular-rate sensors, microelectromechanical system (MEMS) sensors, inertial measurement units (IMUs), and autopilot modules. The effectiveness of these technologies, integrated in competent munitions systems, against ground targets is being evaluated using the 2.75-in. rocket as a test vehicle.

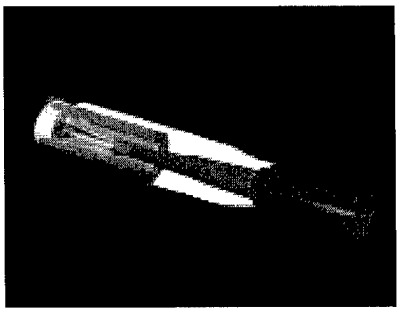
Imapct: ARL research in structures and aerodynamics and guidance, navigation, and control will maximize the on-target effectiveness of direct-fire and indirect-fire munitions.

Electric Armaments

Electric armaments technologies relate to the concept of launching projectiles using electrical energy, either exclusively (electromagnetic (EM) propulsion) or in conjunction with chemical energy from propellants (electro-thermal-chemical (ETC) propulsion).

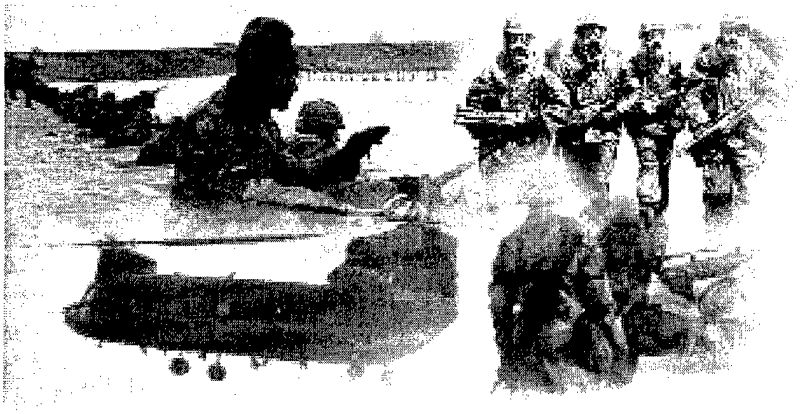
In ETC propulsion, the joint Army and Defense Threat Reduction Agency program has proved ETC propelling charge design. ARL has also studied the fundamental physics and chemistry of plasma-propellant interactions. This has included the development of a plasma-propellant interaction chemistry model, computational fluid dynamics simulation of a simplified plasma jet, and the elucidation of chemical reactions between plasma components and propellants.

In EM propulsion, continued progress was made in pulsed-power technology for EM launchers. Performance of the subscale compulsator, a rotating-machine pulsed-power concept selected for EM launchers has been fully characterized, and a final report was completed. Continued EM launch research will concentrate on developing wear-resistant railgun materials and a 40-mm launch package that can launch a tungsten long rod (length/diameter ratio of 20) at 2.6 km/s with a 50% parasitic mass.



Another element of the Electric Armaments Program is the investigation of the relationship between hypervelocity and projectile lethality. Experimental evaluation was conducted to explore the potential for novel hypervelocity penetrators to defeat advanced armors.

Impact: ARL's investigation of electric armaments technologies offers potential leap-ahead capabilities to defeat future threats, including those equipped with reactive armor and active protection systems.



Modeling the Air Warrior Ensemble

ARL, in conjunction with the Program Manager for Aircrew Integrated Systems (PM ACIS), is developing new techniques for modeling the impact of the aviator ensemble on system operation and performance. The purpose of the models is to examine conceptual clothing systems early in the design stage. At present, there are no techniques to assess the operational effectiveness of new designs until actual clothing components are available for testing with real people. Consequently, problems with new designs are not discovered until considerable time and resources have been expended.

In FY99, the first-ever models of an aviator in a concept ensemble were created with JACK—the human figure computer program—and are being used to aid the analysis of current and future crew-station designs. The model of the aviator can be readily inserted into 3-D models of the future systems to examine the reach envelope and space required for the aviator and equipment. In addition, we are using new techniques to digitize the interior of older helicopters so that analyses can be performed on the computer rather than with the real aircraft.

Impact: These improvements to the modeling process will enable early analysis of crew-systems interactions in a virtual prototyping environment to optimize system performance and reduce development cost. In recognition of the significance of these achievements, the Air Warrior team received the MANPRINT Practitioner of the Year Award.

Visualizing Uncertainty in Automated National Missile Defense Environments

Working with the University of Illinois Urbana-Champaign (UIUC), ARL has developed advanced graphic display concepts to improve the operator's situation awareness and decision-making performance in the National Missile Defense (NMD) environments. During FY99, we also have preformed two experiments: one in Colorado Springs with 16 trained NMD personnel and the other at UIUC using 30 military reserve personnel. The Colorado Springs experiment verified improved methods of displaying probability and showed significant effects related to prior intelligence and inventory control. The experiment performed by UIUC researchers uncovered operator biases and crucial design information resulting from operator comments.

The results of the experiments verified the efficacy of many of the original visualization concepts and led to the development of more advanced concepts to be evaluated later this year. Other important issues to be addressed are the problems of display overload and stress and their interactive effect on decision-making biases previously identified in the literature. The resulting visualization concepts are being evaluated by NMD user groups.

Impact: The general principles should be equally effective for the Future Fires Command and Control system, theater missile defense, and other future command and control systems with significant automated components.

Virtual Environments for Dismounted Soldier Simulation, Training, and Mission Rehearsal

As part of an Army Science and Technology Objective (STO) to develop virtual environments that dismounted soldiers can use for simulation, training, and mission rehearsal, ARL is responsible for providing an individual soldier mobility interface device to control movement through the virtual environment. The mobility interface device must provide a realistic perception of movement, and the energy expended to move in the virtual environment must be equivalent to the energy expended to move across the same terrain in the real world.

The goal of one part of this project in FY99 was to improve the control system of the Omni-Directional Treadmill (ODT) developed by Virtual Space Devices, Inc., so that users perceive their motion as natural. We have developed and implemented a new control algorithm for the ODT based on a lumped-parameter model of the device. This control algorithm along with reductions in sensor noise have greatly improved the performance of the device. Users sense that movement on the ODT simulates locomotion more realistically than the old control system. Future efforts to refine the control algorithm will rely heavily on modeling and simulation. Then experiments to assess users' performance will be conducted to quantify the improvements over the baseline system.

Impact: These efforts, combined with the efforts of our STO partners at the Army Research Institute (ARI) and the Simulation, Training and Instrumentation Command (STRICOM), will lead to simulators that provide dismounted soldiers with a realistic experience, whether it is for training, mission rehearsal, or simulation of future combat systems or tactics.

Effect of 3-D Audio Displays and Automatic Speech Recognition on Soldier Performance

One possible means of improving the negative effects of operator information overload in complex environments is the proper implementation of advanced audio display and control technologies such as 3-D audio displays and automatic speech recognition (ASR). Previous research on Army helicopter pilots, armor crewmen, and dismounted soldiers quantified the benefits of 3-D audio.

In FY99, a study was conducted to quantify the extent to which 3-D audio and speech recognition operate together in a complex, dynamically changing simulated tank environment with high levels of noise and stress.

The results indicated that 3-D audio technology enhances the ability of the soldier to understand and respond to speech communications from multiple channels. Soldiers using 3-D audio were able to correctly identify almost 50% more radio messages than those using monaural displays. Results also indicated that ASR provided over 90% recognition of soldier speech commands to change radio channels and make spot reports, even in high-noise conditions with high levels of workload.

Impact: The data from this research support several programs, most notably Land Warrior and the Crew Integration and Automation Testbed (CAT) Advanced Technology Demonstration (ATD). Application of the research is being extended to the Virtual Cockpit Optimization Program (VCOP) and to the Tank and Automotive Research, Development and Engineering Center (TARDEC) Future Combat Vehicle to improve crew performance in advanced air and land combat vehicles.

Revitalizing Battle Staff Training With Experimental Training Technology

The well-integrated and structured threat to national security has given way to the emerging reality of an *asymmetrical* operational environment (ill-structured, unpredictable, and with multiple focus points) for U.S. Army battle staffs. Success will require the ability to *expect the unexpected* and to avoid predictable actions on our part. Flexibility and adaptive thinking will be valued to a greater degree than ever before. While we believe that emerging technology can support this requirement through the digitization of the operational environment, an opportunity also exists to exploit new technologies to support emerging learning models.

This project demonstrated how new technologies can provide a PC-based simulation to enhance problem-solving skills more effectively and earlier in career development. The prototype training tool, ACUMEN (Advanced Cognitive Understanding of Military Environments), implements a training strategy drawn from research that specifically promotes flexible thinking and stronger transfer of learning to the operational setting. ACUMEN allows the user to explore multiple problem-solving iterations through an interactive interface and the integration of simulation technology. The game-like *look and feel* of ACUMEN provides motivation and support for the officer who has developed an initial competency in military science to begin experiencing the nuances of the military art.

During development of the ACUMEN prototype, the strength of the learning theory was successfully demonstrated in small group training at the U.S. Army Command and General Staff College at the request of TRADOC's Army Experiment 6 (AE6). The prototype is currently undergoing usability testing that will provide the foundation for further development that has already been funded by TRADOC.

Impact: The prototype tool completed in this effort provides a model for how new technology can support emerging requirements, and further development of a more fully operational tool will provide an easily accessible method to support successful performance in the emerging complex, digitally supported environments.

Application of Innovative Human Factors Methods to the XM777 Howitzer Acquisition Program

ARL developed and applied innovative human factors methods during the XM777, 155-mm, lightweight, towed howitzer acquisition program to increase system safety, usability, and efficiency while avoiding costly redesigns and reducing the total cost of ownership. These methods included an early human factors engineering (HFE) evaluation, human figure modeling, task network modeling, and the development of alternative system components.

The early HFE evaluation identified numerous operator-system interface concerns and the subsequent corrective actions were managed through an innovative human factors tracking log developed and maintained by ARL.

Human figure modeling was used to correlate reported operator discomforts with specific crew postures interfacing with the prototype design. Subsystem design alternatives related to handwheels, trails, spades, and fire control were evaluated through this modeling effort.

Task network models were generated with the Improved Performance Research Integration Tool (IMPRINT) for various response functions. The modeling results were used by the Joint Program Manager for requirements risk reduction, by the training community for crew drill optimization, and by the prime contractor to conduct real-time design trade-offs on over two dozen subsystem alternatives.

ARL also developed, fabricated, and evaluated a Fast Azimuth Shift Tool to reduce crew burden and function time for conducting the bold-shift function. The concept and design was immediately implemented into the final howitzer design due to the success of the evaluation.

Impact: The development and application of all four innovative human factors methods significantly impacted the safety, usability, and efficiency of the XM777 howitzer. The timeliness of the early human factors evaluation provided the Joint Program Manager and contractor sufficient time to implement corrective actions. The models and simulations of operator-system interactions enhanced the evaluation of specific design alternatives at a significantly reduced cost and schedule.

Cognitive Engineering of the Digital Battlefield

In 1998, ARL undertook a systematic investigation of the impacts of digital information system technology on battle command operations at the battalion through corps levels. The goal of this multiyear research program has been to integrate a broad set of theories and models from the fields of cognitive psychology, organizational psychology, complexity theory, military history, and human factors into a unified understanding of how digitization will evolve and improve the military decision-making process. While first-year efforts focused on better understanding individual decision-making strategies, research in 1999 shifted to the study of information management and decision making at the team and organizational level.

During 1999, ARL partnered with the Defense Advanced Research Projects Agency (DARPA) in its Command Post of the Future program. Through this effort, ARL and DARPA are jointly exploring new paradigms and approaches for structuring the commander's knowledge space. Throughout 1998 and 1999, ARL has continued to support battle command research at several TRADOC Battle Labs, including specific projects at Ft. Leavenworth, Ft. Knox, Ft. Sill, and Ft. Hood. At the same time, ARL plays a continuing role in the design of headquarters operations and facilities for the Army's emerging Strike Force concept. Finally, over the next several years, research activities will continue to support the Army's Experimentation Campaign Plan, including the evaluation of information system technology during both the Joint Contingency Force Warfighter and the Digital Capstone Exercise.

Specific findings from this research have already been incorporated into the Capstone Requirements Document for the Army Battle Command System (ABCS). ARL research findings have also contributed to the most recent rewrite of Field Manual 100-34, Command and Control.

Impact: Through this work, ARL is providing the Army with human-centered design guidance for the design and evaluation of future information system architectures for battle command.

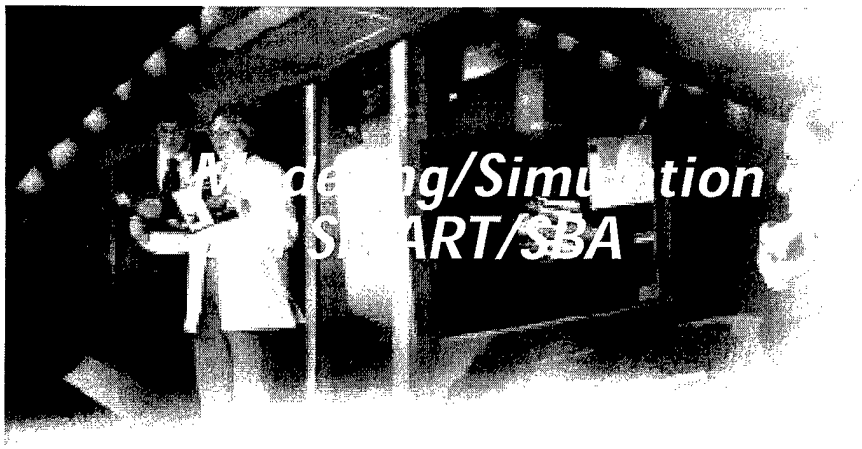
CoHOST: Modeling On-the-Move Command and Control

The Tactical Operations Center (TOC) of the future is being designed with the expectation that soldiers can perform their command and control (C^2) and staff functions while on the move. The need for this capability was identified during Desert Storm. In FY99, ARL scientists created a dynamic model representing a heavy maneuver Battalion TOC to provide system developers and testers with the answers to two key questions: Can C^2 keep up with the main fighting force? Can TOC soldiers perform their C^2 duties effectively in a moving vehicle and over a 24-hour period?

MODELING/SIMULATION and SMART/SBA

The C^2 Modeling Team built upon existing stationary TOC models. The new model, CoHOST (the Computer Human Operator System Task Flow Model), handles a 24-hour tactical events scenario and calculates the distance between vehicles to ensure they remain within communications range. Human performance degradation factors were developed to reflect the impact of fatigue, noise, and vibration on soldier performance in the C^2 environment. The discrete-event simulation model includes a visualization window where one can watch the on-the-move scenario unfold as information is processed by C^2 soldiers. The CoHOST model clearly portrays that, on the move, certain tasks take much longer to perform and more incoming information is left unattended than during a stationary operation.

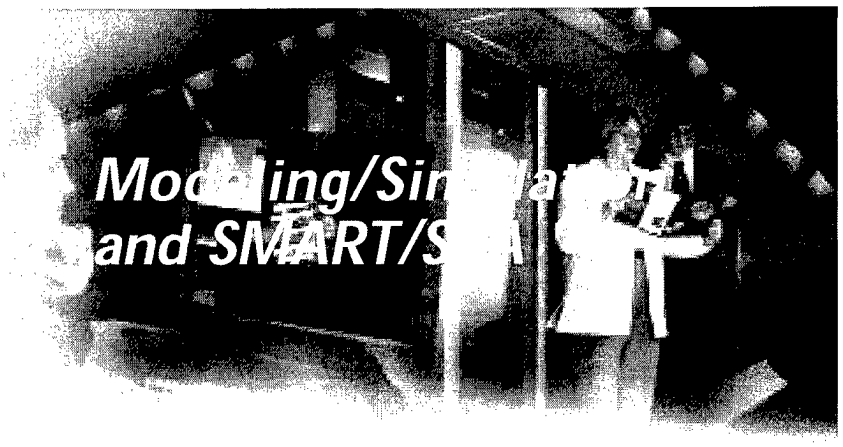
Impact: CoHOST can be used to generate a current C^2 soldier performance baseline and systematically examine changes to force structure, doctrine, and technology for the near term and for advanced and visionary concepts.



Manufacturing Process Modeling and Simulation Technology for Large Scale Composite Structures

The prohibitive factor in the development and acquisition of new composite structural weapon systems is in the cost, primarily because of the limited experience in the manufacturing process. Of the various structural composite manufacturing processes, composite net-shape liquid composite molding (LCM), such as the resin transfer molding (RTM) or its variants such as vacuum-assisted RTM, permits repeated manufacturing of complex composite structures with desired fiber orientations to obtain directional properties. These processes also allow for assembly of smart structures to assess service life and provide for damage detection. The process, however, involves repeated trials and errors to determine a working production methodology, thereby increasing the production lead times and cost. Concurrent engineering and process modeling methodologies and simulations based on physical and mathematical modeling of the process provide the necessary engineering tools to determine the optimal process parameters, and the design of tooling and molds. The integrated modeling environment, coupling the design, process simulation, and structural integrity analysis, serves as a design and production methodology for composite structures. It impacts the acquisition of various new weapon platforms for the Army and develops a science and technology base for composite processing technology.

Impact: Many new DoD systems such as the RAH-66 Comanche helicopter, the Composite Armored Vehicles (CAV) and the Joint Strike Fighter (JSF) employ structural components made up of fiber-reinforced composite materials. These tend to be lightweight and provide the required battlefield survivability, lethality, and operational readiness. Acquisition of such composite materiel systems poses significant problems due to the associated cost and time for the development and maturation of the associated manufacturing processes. The current research efforts develop and provide a simulation-based solution employing DoD high-performance computing resources toward reducing the cost and time of the development and streamline the acquisition of composite weapon structural components.

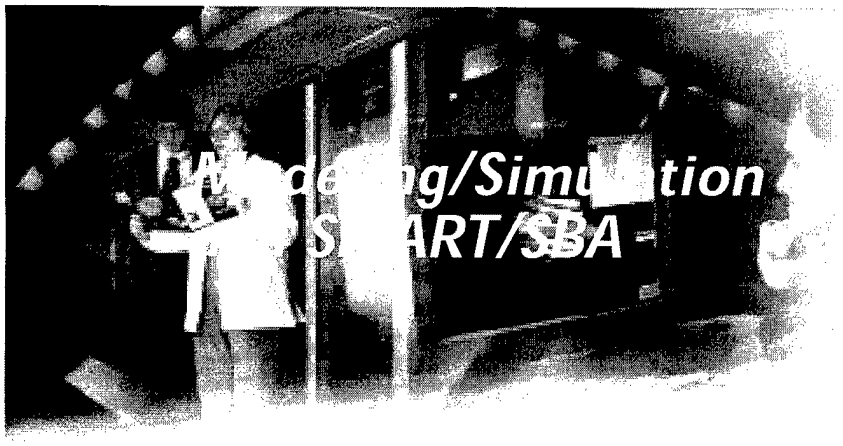


IMPRINT—The Improved Performance Research Integration Tool

IMPRINT is a stochastic network modeling tool for soldier-system simulation. It is designed to assess the interaction of combined soldier and system performance throughout the system life cycle—from concept and design through field testing and system upgrades. Outputs include mission, function, and task performance times and failures; degraded performance effects resulting from factors such as heat, cold, and protective clothing; personnel skill and aptitude requirements; mental workload levels; crew size and function allocation recommendations; and maintenance manpower recommendations. It makes extensive use of embedded human performance algorithms and libraries of soldier-system performance data. IMPRINT has been used to feed concept decisions, analyses of alternatives, technology trade-offs and down-selects, hardware and software design decisions, and personnel and training decisions.

Key FY99 advances in IMPRINT research and development are on several fronts: IMPRINT served as the testbed data for the Air Warrior development of performance degradation algorithms, one of ARL's top five efforts this year. IMPRINT was also a key focus of a cross-service investigation into the state-of-the-art in manpower, personnel, and training requirements estimation models. In another cross-service effort, IMPRINT is being used as the human performance component of an Air Force-led Defense Technology Objective to develop models for SBA and, as a result, IMPRINT will be integrated with a multisimulation, HLA environment in the FY00–FY01 timeframe; thereby laying groundwork for the future of system design and acquisition. Last, but perhaps most critically for IMPRINT's future contribution to soldier-system simulation, research into compatible cognitive modeling architectures at the *atomic* level was initiated.

Impact: IMPRINT will provide both a depth and breadth of modeling and analysis capabilities, including modeling concepts today for systems to be fielded well into the 2010s.

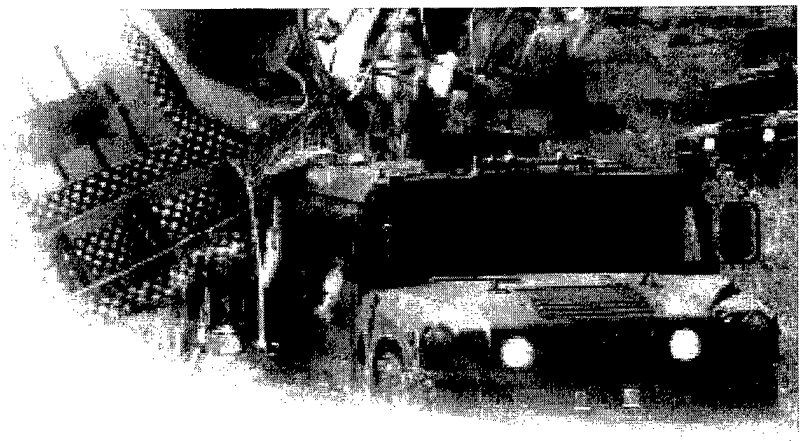


Configured Load Unit Building Model

ARL has a long history in modeling to support logistics. Perhaps the most well-known is a theater-level modeling tool, the Knowledge Based Logistics Planning Shell (KBLPS). During FY99, KBLPS added the capability to model enemy logistic infrastructures with the goal of analyzing which nodes to target for maximum effect on the enemies logistic pipeline. However, the new thrust in ARL's logistics modeling is research and development of unit-level models for force design, specifically, the Configured Load Unit Building Model (CLUB).

Using the latest in object-oriented discrete event simulation, CLUB models the unit and force structure reconfiguration required by the introduction of new technology, in this case, changing from strategic-configured loads to mission-configured loads through the use of new material handling equipment such as the Container Roll in/Out Platform (CROP). The CLUB modeling effort, carried out in coordination with the Combined Arms Support Command and the Defense Ammunition Logistics Agency, provided key data for analyzing equipment alternatives for acquisition; designing the unit and force organizational structure, and, once the equipment is acquired, preparing units to receive the new equipment. Future objectives to accommodate the decreasing military workforce and the increasing mission scope and battlefield scale are to incorporate the additional factors of personnel mix, multiple equipment assets, and equipment failure rates. In the out years, the CLUB will be used to identify logistic process bottlenecks and aid technology and combat developers in the simultaneous analysis of equipment and force structure alternatives.

Impact: CLUB provides the immediate capability to assess the impact of the insertion of configured load technology on unit-level organizational design requirements.

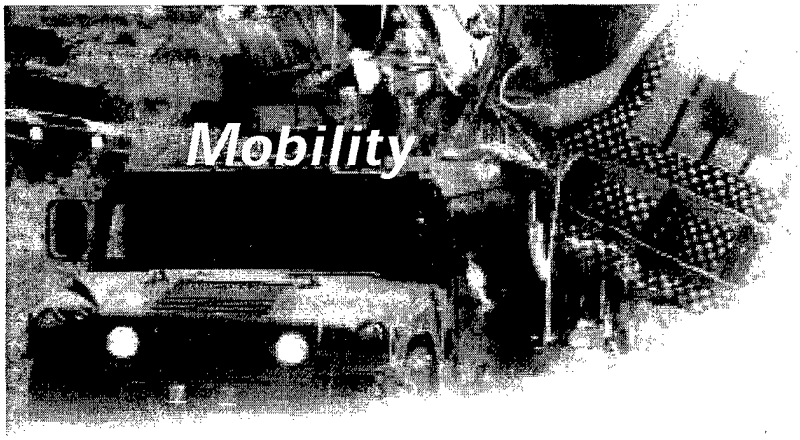


Oil-Free Turbomachinery

Oil-free turbomachinery capitalizes on recent breakthroughs in foil air bearings, tribological coatings, and computer-based modeling to create dramatically improved turbomachinery systems that can operate at higher speeds and higher temperatures without the need for conventional bearings, lube systems, or cooling. In FY99, at the Schwitzer Turbocharger plant in Indianapolis, an oil-free turbocharger ran successfully in a 5-hour demonstration test over its entire normal operating range (up to 95,000 rpm and 1,200 °F). The turbocharger performed flawlessly, presenting no operational problems or limitations whatsoever. This demonstration was a first critical step in the oil-free turbomachinery program, which has the goal of develop-

ing revolutionary, yet practical, oil-free aeropropulsion engines. The next step is an oil-free general aviation propulsion (GAP) class turbine engine. Combined with aggressive in-house oil-free technology research, these two demonstrations will set the stage for truly revolutionary aeropropulsion technology improvements.

Impact: Doing away with the oil lubrication system eliminates up to 15% of engine weight and 50% of the engine maintenance. Foil bearings operate comfortably at 1,200 °F and bearing cooling is unnecessary, yielding further weight and cost savings.

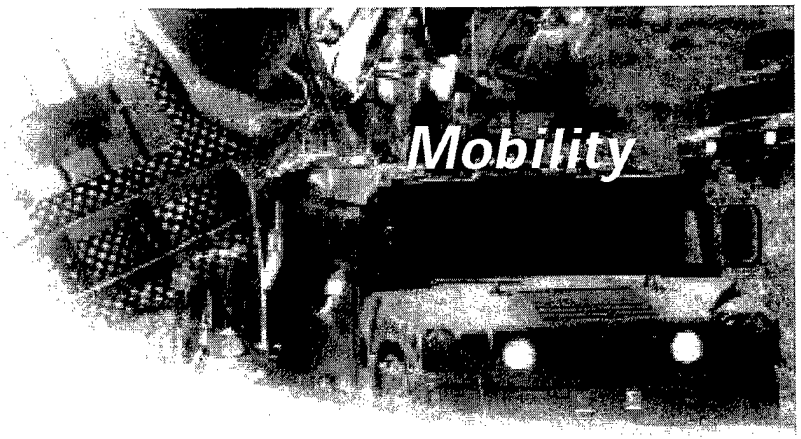


Highly Mobile, Two-Passenger Hybrid Electric-Drive Vehicle

The ground vehicle structural dynamic research addresses mobility issues that focus on advanced concepts for improved vehicle response characteristics using advanced control methodologies and algorithms. MONGREL is a high-mobility, two-passenger, hybrid electric-drive experimental vehicle that is under development through the Small Business Innovation Research (SBIR) program. An added benefit of MONGREL is its high degree of component commonality, which reduces the amount of materiel required for support and shortens the logistics tail. The MONGREL design features an actively controlled swing-arm suspension that is common to all wheel locations. In-wheel electric motors power each wheel independently, and the steering is achieved by differentially powering the electric motors in lieu of laterally turning the front wheels. Wheel speed and suspension control are performed using a computer-driven fuzzy logic controller. Since the vehicle is essentially electronically controlled, a joystick-like controller is used for speed and directional control.

MONGREL's development was delayed in FY99 because of problems with the in-wheel electric motors. These have been addressed and the motors should be in the evaluation stage soon. The frame for MONGREL is complete, and the composite body is in fabrication and will be ready by the beginning of FY00. Redesign of the vehicle's cab interior has begun, including a total redesign of the dash to incorporate touch-screen computer displays. Active suspension control logic has been successfully demonstrated on a one-wheel test stand with the fuzzy logic controller. Enhancements to the hydraulic pumps to increase performance and reduce size have been initiated. Development has begun on the operator control logic for the joystick. Vehicle testing should occur in December 1999, with delivery by mid-FY00. Discussions were initiated by NASA's Jet Propulsion Laboratory (JPL) to incorporate its new ethanol fuel-cell technology in MONGREL and to compare its operation with the existing conventional generator.

Impact: MONGREL will incorporate technologies needed to enable the mobility capabilities required of future AAN vehicles. These include traversing rough terrain at 60 mph and achieving highway dash speeds of 100 mph.



Four-Port Wave-Rotor Experiment

The wave rotor is a turbomachinery component that accomplishes the compression and expansion processes of a high-pressure spool (i.e., a gas generator or gasifier) within a single component. The wave rotor is self-cooling and aerodynamically compatible with the low corrected flow rates supplied by the compressors of modern high-pressure-ratio turboshaft engines. The wave rotor can be embedded concentrically between the high-pressure compressor and high-pressure turbine to increase the overall pressure ratio of the gas turbine engine by a factor of three and the peak temperature by 25%, without increasing the temperatures of the rotating machinery components.

In FY99, a four-port wave-rotor component, of the type that could be used to top future advanced gas turbine engines, was successfully tested at the NASA Glenn Research Center. A series of experiments were carried out that established the first operating map for a four-port through-flow wave rotor and this marks a major milestone for the ARL/NASA wave-rotor project. The wave-rotor pressure ratio—a measure of performance—was found to be in qualitative agreement with numerical predictions from in-house computational fluid dynamic (CFD) codes. The performance levels were lower than anticipated, but this has been attributed to augmented heat transfer between the rotor and the working fluid. The in-house CFD tool for wave-rotor design and analysis has been improved and further validated with the on- and off-design data generated during the experiments. The wave-rotor operating map and the validated CFD tool are deliverables that will be key to future wave-rotor technology development.

Progress was also made toward the planned demonstration of a four-port wave rotor within a small turboshaft engine, thanks to a contract effort with Rolls-Royce Allison. Building upon work from previous years, the mechanical design of the wave rotor *rotor* was initiated. The work includes preliminary design and detailed heat transfer, stress, and structural dynamics analyses.

Impact: The wave-rotor thermodynamic increases will translate into significant gas turbine engine power and efficiency enhancements. For example, the wave rotor is predicted to increase the specific power of the Allison 250 helicopter engine by 18% while reducing the specific fuel consumption by 15%.

Durability and Damage Tolerance of Rotorcraft Structural Components

The technical challenges for composite structures in rotorcraft are to (1) ensure structural integrity while making extensive use of composite materials, (2) provide cost competitiveness with aluminum, and (3) provide low-initial design and manufacturing costs as well as substantially reduced life-cycle costs. To achieve efficiency and affordability one needs to consider both the airframe and dynamic components of rotorcraft structures. Low-cost structural design concepts along with reliable analysis and design methods

that are based on durability and damage tolerance and residual strength will lead to efficient and affordable airframe structural concepts.

In FY99, ARL investigated various methodologies to address vital composite design issues, including (1) transverse tension strength characterization, (2) influence of ply waviness on fatigue durability of composite rotor hub flexbeam laminates, and (3) durability and damage tolerance design criteria for composite skin/stringer airframe components under multi-axial loads. In the area of transverse tension strength characterization, three- and four-point bend tests were performed on 90° lamina. It was found that polishing specimen edges and bottom failure surfaces resulted in lower strengths, and that larger spans also yielded lower strengths. These strengths were under-predicted by a classical Weibull Scale law. The work on fatigue durability of composite rotor hub flexbeams identified the significance of fiber waviness amplitudes and location on fatigue life, and initiated a parametric study on acceptable waviness levels. The influence of combined membrane and bending loads on pull-off composite skin/stringer airframe components was successfully predicted. In addition, a simplified technique for generating energy-release rates for delamination in components with nonlinear deformations was developed to reduce the analysis time needed for parametric design studies.

Impact: This in-house research will provide validated design tools to support the Aviation and Missile Command (AMCOM) Rotary Wing Vehicle structures technical objectives and the DoD's goals and payoffs. It is also a critical part of a multiyear joint effort with the NASA Design for Efficient Affordable Rotorcraft (DEAR) program.

Reliability and Durability for Ground Vehicles

Lightweight armor, advanced structural concepts, improved ballistic performance, more durable structures, low-cost manufacturing, and reduced operation and support costs are essential to achieving the vehicle performance and affordability goals of the next generation of Army ground vehicles. The incorporation of advanced materials such as lightweight metals, ceramics, composites, and energetic materials will require advances in structural modeling and inspection methods to accurately predict, measure, and resolve structural issues.

We are addressing these needs by providing new and improved reliability and durability technologies. Our research is developing and validating advanced structures technologies that focus on improved damage tolerance, durability, and reliability of innovative armor/structure configurations. The structural integrity research focuses on advanced inspection methods for complex armor/structure configurations. Nondestructive evaluation (NDE) methods and hardware are critical for future combat vehicle developments to (1) ensure that a practical inspection capability is integrated with the vehicle design process; (2) provide quality assurance during manufacture; and (3) guarantee reliability, durability, and safety for vehicle operations and support. Advanced NDE methods that are being evaluated include computed tomography, microwave, laser ultrasonics, and embedded sensors.

In FY99, we incorporated a new focal plane array technology into a portable unit that increased inspection resolution of thick composites. In addition, microwave NDE of a ceramic structure was applied to calibrate durability using reflection coefficient measurements. Finally, a laser-based ultrasound system was tested on large composite/hybrid structures to evaluate new noncontacting NDE methods for reducing inspection times and enhancing field inspection capabilities.

Impact: These NDE measurement sciences can be used to evaluate and validate new armor/structure concepts for the TARDEC Integrated Armor/Structures for Light Weight Vehicles STO. NDE analyses and tests will enable the designer to simulate flaws at critical locations and to estimate the probability of detection and, hence, improve system reliability and durability.

Innovative Composite Fuselage Design for Improved Crashworthiness

Advances in occupant protection in crash conditions for future Army vehicles will require not only improved modeling and simulation tools, but a better understanding and application of energy-absorbing structures to protect the occupant space. ARL and NASA are engaged in a multiyear cooperative research program to develop and evaluate an innovative and cost-effective composite fuselage concept for improved crashworthiness. The fuselage was designed to satisfy the primary goals for crashworthiness: (1) limit the impact forces transmitted to the occupants, and (2) maintain a livable volume space for the occupants. In FY97 and FY98, the fuselage concept was demonstrated through fabrication and testing of a 1/5-scale model, leading to the final evaluation of a full-scale prototype in FY99. By choosing the scale model tests first, a secondary objective of the research project was to investigate the application of scale model testing for composite structural design. The fuselage consists of a relatively rigid upper section, or passenger cabin; a stiff structural floor; and a frangible lower section that encloses the crash energy management structure.

In FY99, construction began on a full-scale version of the fuselage concept. Following curing, the energy-absorbing subfloor was fabricated and mounted to complete the fuselage construction. Suitable lead weight was added to the floor to represent the inertia of occupants, seats, and other masses.

A vertical drop test was conducted at 31 ft/s impact velocity onto a rigid impact surface. Average floor-level accelerations of 28 g were measured, which were very close to the original 25-g design goal. No damage to the upper section or floor of the fuselage was observed. A second drop test is planned to determine the off-axis behavior of the energy-absorbing subfloor. Once the impact tests are completed, a comparison of the 1/5-scale model and full-scale test data will be made to characterize any scaling effects in the impact response of the fuselage concept.

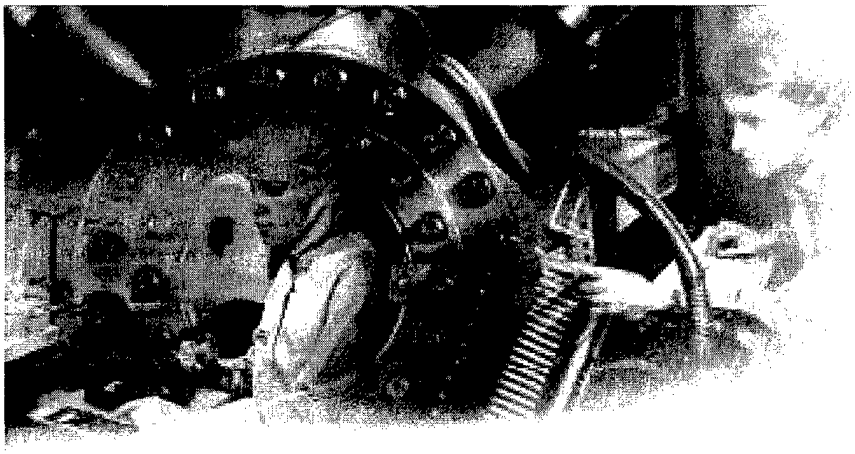
Impact: This research paves the way for an innovative concept of aircraft fuselage structural design that can realize crashworthiness goals and objectives while avoiding the reliance on after-design modifications.

Full-Scale Crash Test of a Sikorsky Advanced Composite Airframe Program Helicopter

A major milestone was accomplished in FY99 with a full-scale crash test of the Sikorsky Advanced Composite Airframe Program (ACAP) helicopter fuselage at the NASA Langley Impact Dynamics Research Facility (IDRF). The ACAP helicopter was developed in the early 1980s as a technology demonstrator for composite technology in a program sponsored by the U.S. Army. This crash test was conducted with the Sikorsky residual flight test article. The primary objective of the crash test was to obtain detailed experimental data to assess the prediction capability of existing nonlinear, transient dynamic, 3-D finite element model methods. The helicopter was dropped from a height of 40 ft, in a pendulum fashion, to achieve the required initial impact conditions onto a rigid impact surface. The helicopter included two floor-mounted UH-60 Blackhawk seats, two ceiling-mounted troop seats, four anthropomorphic dummies, and triaxial locking mechanisms for the pilot and co-pilot restraint systems.

A photographic time-sequence of the helicopter drop test shows the helicopter impact with a 6.25° nose-up pitch and 3.5° left-low roll. The structure reacted as designed, with fractures evident in the roof beams, but only minor reductions in the occupant's livable volume. Preliminary indications suggest that the crash was severe, but survivable.

Impact: These tests have provided carefully collected experimental data for correlation and validation of MSC/DYTRAN, one of the several nonlinear transient dynamics codes typically used for crash simulations. As a consequence, future crashworthiness design efforts will be far more accurate and reliable.



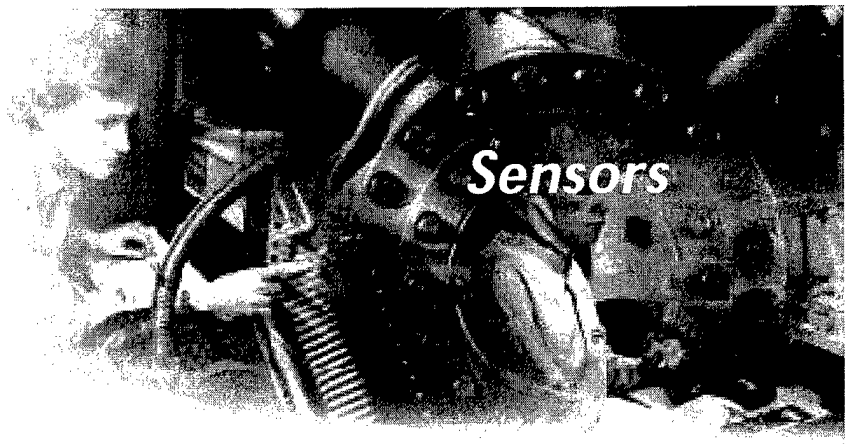
Real Aperture Radar

ARL has developed a technique that uses a neural network to fine-tune the trained target detection algorithm parameters based on the clutter characteristics received by the radar. This adaptive detector is now the primary candidate for a block improvement program proposed by the PM-Longbow. The Longbow radar contractor team, ARL, and the PM Office are working effectively to develop a transition approach for ARL's technology.

In one illustration of this concept, the performance of three algorithm training and testing approaches—site-specific, universal, and adaptive detection—can

be described. The site-specific curve would show the radar's performance if the stationary target identification (STI) detection algorithm is trained on a specific test site (e.g., Aberdeen Proving Ground (APG)) and then tested at the same test site (e.g., APG). The universal detection algorithm would be trained on three test sites to generate an *average* set of algorithm coefficients. The universal curve would show the radar performance if this algorithm is then tested at a new test site (e.g., APG). The adaptive detection performance curve would show the radar's performance if it is trained on three test sites than tested at a site that the radar had never viewed before (e.g., APG).

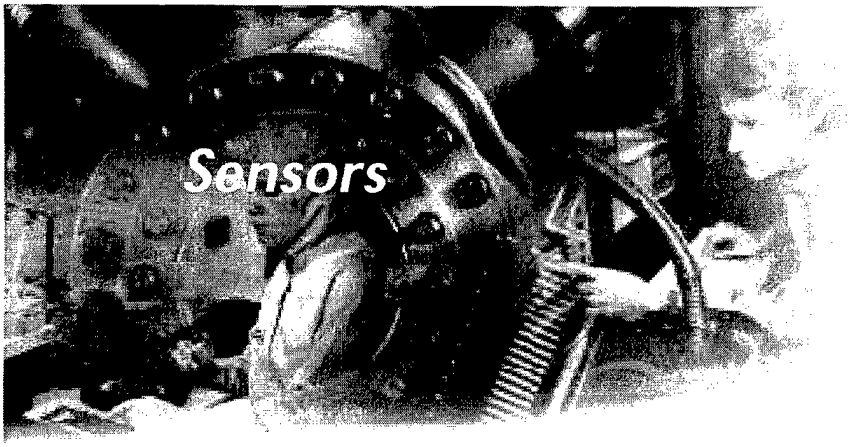
Impact: This ARL-developed approach increases the robustness of real aperture radar STI algorithms by autonomous adaptation of the target detection algorithms to clutter received by the radar.



The 10-GHz Ferroelectric E-Scan Antenna

Two of three modular pieces, the 4 × 16 element antenna and the divider network, for the 10-GHz ferroelectric E-scan antenna have been designed, fabricated and partially characterized. The second iteration of the antenna, a 4 × 16 element aperture-fed patch antenna, provides the necessary bandwidth, greater than 10% at 10 GHz and a voltage standing wave ratio (VSWR) of 2:1. The original design of the divider network was within 2 dB of the theoretical insertion loss with 30 dB isolation, 7 dB input reflection, and better than 10 dB of output match. While improvement in the phase shifters is still required, it should be noted that the program has established capabilities for in-house fabrication and microwave characterization of materials and devices as well as the ability to fabricate ferroelectric phase shifters (although cutting precision and tolerance need to be improved).

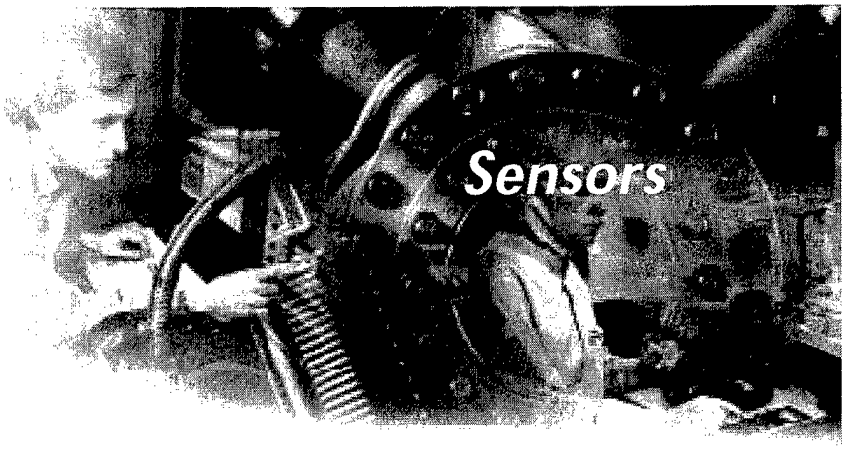
Impact: This program will provide the Army with a low-cost horizontal electronic scanning capability at 10 GHz for active tank protection.



Acoustic Physiological Monitor Patent

A third patent was issued as a result of the Acoustic Physiological Monitoring program. U.S. patent No. 5,853,005, *Acoustic Monitoring System,* was issued on December 29, 1998, to Michael V. Scanlon and ARL. This very extensive patent (96 claims) covers many military and civilian applications of the fluid-coupled acoustic sensor. All three patents have been licensed by two companies for commercialization of a Sudden Infant Death Syndrome/Apnea monitor and an athletic performance monitor. Royalties and licensing fees already received at ARL have been applied to various programs. Scanlon received the distinguished IEEE-USA Electrotechnology Transfer Award for the Patent License Agreements and CRDA relating to this technology.

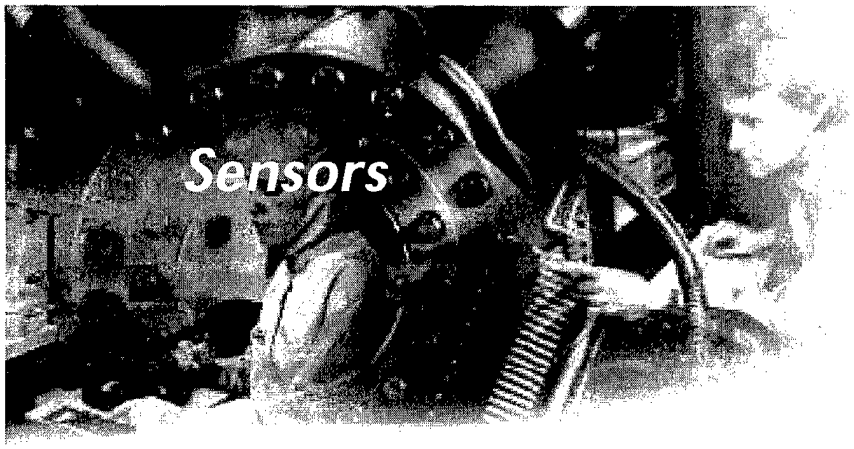
Impact: An ongoing ARL program is applying the same technology to monitor the health and performance of soldiers in the battlefield. By having a sensor contacting the soldier's body, the fluid-coupled sensor is optimized to pick up human sounds very well, yet rejects ambient noise through acoustic impedance mismatches between the air and the sensor. This body-worn sensor can monitor the soldier's health, voice, and activity, and relay this status information to a medic or commander as needed for remote triage or readiness assessment. A new TPA between ARL and NRDEC/ARIEM will ensure transition of this technology to the Warfighter's Physiological Status Monitor program within MRMC. Technology also has potential for Land Warrior and MOUT.



New Materials for High-Energy Capacitor Electrolytes

Scientific guidelines were established for the formulation of new organic-solvent-based electrolytes for electrochemical capacitors. The guidelines were used in the selection of suitable molecular structures for novel component salts and solvents. A number of the molecularly designed salts and solvents were synthesized and pertinent chemical and physical properties were evaluated. Based on the measured properties, a number of the candidates are expected to provide electrolyte formulations that will increase capacitor energy density by upwards of 50% and provide performance down to –40 °C. Some of the new solvents are expected to be applicable to rechargeable Li-Ion batteries as well as to capacitors. For batteries, the new solvents will provide reduced risk of flammability, higher power, and lower operating temperatures.

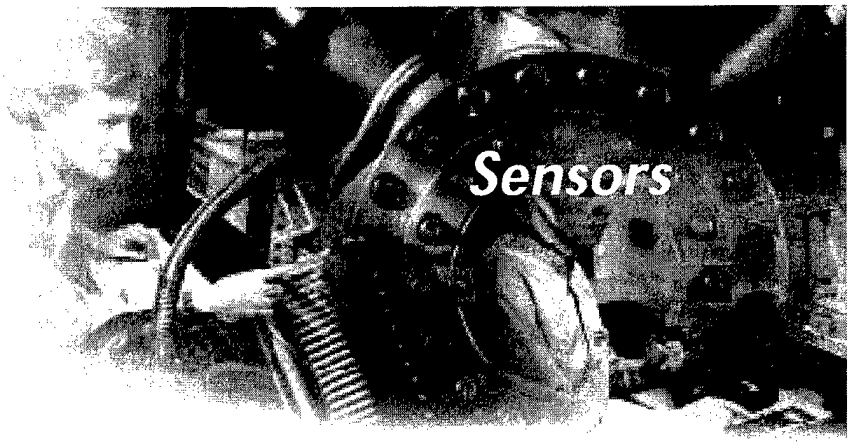
Impact: Electrochemical capacitors with high energy density and low operating temperature are being sought for such Army applications as assisted engine starting (TACOM) and burst communications (CECOM) and load leveling of batteries and fuel cells (CECOM). The civilian sector is also seeking improved capacitor performance for similar civilian applications where the low temperature performance requirement can be relaxed, but other requirements may not.



Dual-Band Infrared Camera

One of the principal components of the notional multidomain smart sensor (MDSS) system is a dual-band forward-looking infrared (FLIR) camera. In co-operation with our FedLab partners ARL has been working to develop a pixel-registered, simultaneously integrating dual-band infrared focal plane array (FPA) as part of the MDSS program. Early in FY99, such an FPA using quantum-well infrared photodetector (QWIP) technology was produced; later in FY99, a dual-band FPA using mercury-cadmium telluride (MCT) photodiodes was produced. These FPAs are simultaneously sensitive to both medium-wave infrared (MWIR, 3- to 5-μm wavelength) and long-wavelength infrared (LWIR, 8- to 12-μm wavelength). The development of dual-band IR detector arrays is an important first step toward the successful demonstration of the MDSS notional system.

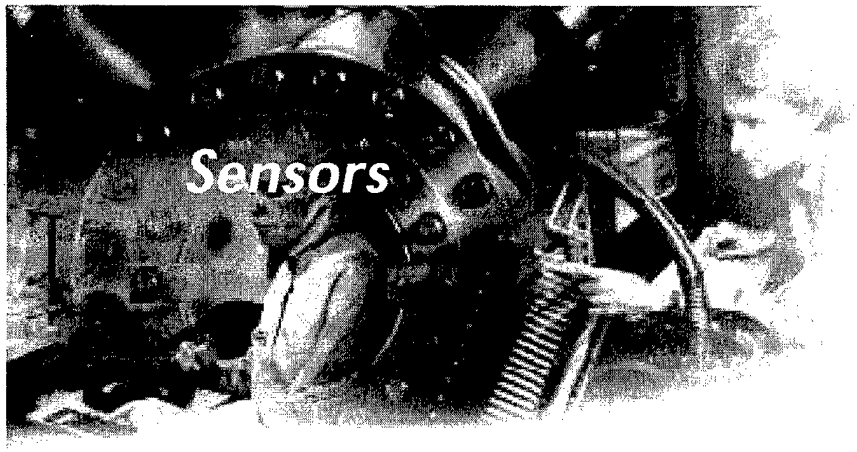
Impact: A sensor system using a dual-band MWIR/LWIR FPA would be able to operate in a wider range of ambient conditions (day, night, fog, smoke, etc.) than the single-band FPAs that are currently available. The imagery from the separate wave bands can easily be fused into a single composite color image that can give the observer more information about a scene than may be obtained from a single-band camera. We have shown that the combination of MWIR and LWIR image data improves the performance of aided/automatic target recognition (ATR) algorithms in detecting and identifying targets over that of single-band FLIRs. This enhanced capability to view the battlefield will greatly increase the system's ability to pick targets out of clutter and to distinguish targets from decoys and defeat other enemy countermeasures.



Testing for Type Classification for PILAR

Over the past year ARL has conducted a number of field evaluations of both the French fixed-site and vehicle-mounted PILAR sniper detection systems. The ARL Sniper Detection Team (SDT) using its vast knowledge of acoustic systems of this type, designed a series of evaluations to stress the systems and to determine if these systems meet the requirements of the SOCOM user. Open-field evaluations were performed in the cold, snow-covered environment found in Ft. Greely, AK, and in the warm, benign, short grass, flat terrain of Aberdeen Proving Ground, MD. An E^3 evaluation was also performed at ARDEC. These evaluations resulted in the identification of a number of system deficiencies, including radio frequency interference experienced by the system when operating in the presence of SINCGARS transmissions, improper acoustic signature identification in snow cover, and general hardware reliability. With these deficiencies the systems did not meet the SOCOM requirements. The SDT, drawing upon its experiences in acoustic signature identification, rf-shielding, and electronic system design, collaborated with the system vendor to pinpoint the source of each of the problems and identify the appropriate enhancements necessary to eliminate the problems. All the necessary enhancements have been implemented in one system of each type and will be implemented in the other units early in FY00. The two enhanced systems have been successfully tested and meet the SOCOM requirements. Solving these problems and having the solutions implemented is a crucial step towards obtaining Type Classification-Limited Procurement (TC-LP) and field the system in the first quarter of FY00.

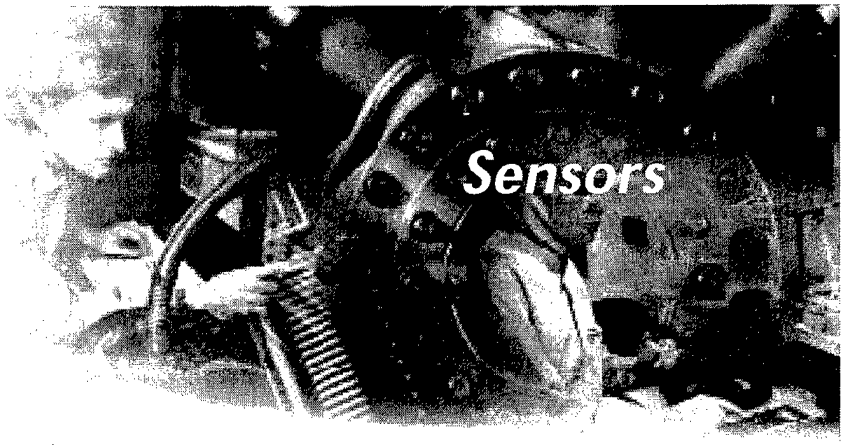
Impact: This project will result in the first U.S. Type Classification–Limited Procurement (TC–LP) of a Sniper Detection System (SDS), in direct response to needs stated by LTG Benton, Chief of Staff, USEUCOM, and by BG Lambert, Commanding General, SOCEUR. Six units (3 fixed-site and 3 vehicle-mounted) of the PILAR system will be fielded with SOCOM troops. These units will represent the initial operational capability in U.S. military inventory (other than a soldier's eyes and ears and the standard-issue optics units). These systems will enhance the force protection capability of U.S. forces and greatly reduce the effectiveness of adversarial snipers. Additional units will be procured and fielded on an as-needed/desired basis.



Smart Pixel Image Transfer

This effort involves the optoelectronic movement and processing of electronic information between electronic-optical interfaces. Significant accomplishments achieved in FY99 included the demonstration of improved discrete vertical-cavity surface-emitting lasers (VCSELs) with reduced threshold voltages (as low as 2.3 V) and reduced threshold currents (as low as 150 μA) that electrically match more efficiently to conventional electronics. The 8 × 8 VCSEL arrays were flip-chip bonded onto CMOS drive circuits, which demonstrated gigabit-per-second-per-channel optical-interconnect data rates to an 8 × 8 flip-chip array of receiving detectors. All the pieces were integrated for the demonstration of a one-to-one imaging OE interconnect between 8 × 8 VCSEL/CMOS and detector/pad arrays. This amounts to a demonstrated 64 gigabit-per-second optoelectronic interconnect data rate. All these results were reported in four papers at technical meetings in FY99 and an invited paper and several contributed papers to be presented in FY00. This technical capability was developed in close collaboration with the University of Maryland and Johns Hopkins University through the ARL Microelectronics Research Collaboration Program (MRCP).

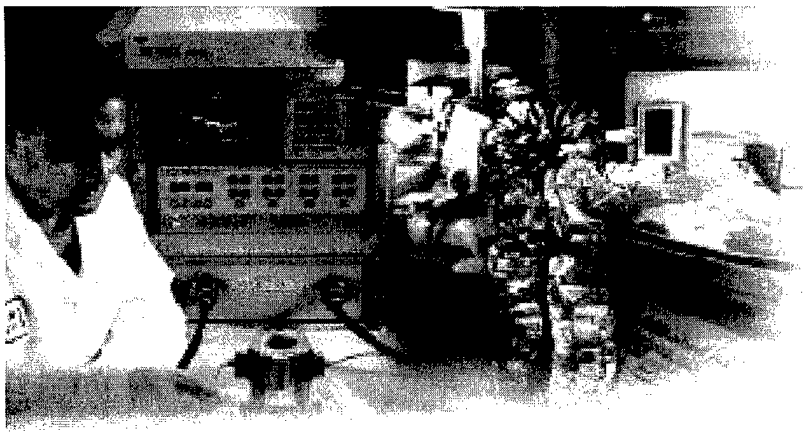
Impact: Army sensors are acquiring data at increasing data rates that are rapidly outstripping the capacity to relay or process the data. Future Army sensors will require smart on-board processing and enhanced interconnect data rates to keep pace with sophisticated emerging sensor technology such as SAR, hyperspectral imaging, ATR, other image processing, and the use of unmanned-aerial-vehicle sensor platforms. These VCSEL optoelectronic interconnects are presently being incorporated into several optoelectronic interconnect and processing demonstrations including parallel-channel image transfer (ARL), VCSEL-array interferometric imaging (U. Illinois), digital-half-tone optoelectronic image compression (U.S. Military Academy), and optoelectronic image pattern recognition (Johns Hopkins U.). This technology is also being transitioned through two CRADAs with small businesses, a Technical Program Annex with AMCOM, a Federated Laboratory interconnect effort, and a Cooperative Agreement with OptiComp (a small business). ARL and AMCOM are administering $16M in DARPA investment in this technology for application to SAR and hyperspectral imaging processing. In FY99 an Army Strategic Technology Objective (STO) was established on this topic to begin in FY00 and run for five years. Future Army sensors will be enabled by this emerging optoelectronic interconnect and processing technology.



Advanced Acoustics Target Recognition

A fundamental frequency tracker was developed to reduce false alarms and continuously provide accurate information about the target's acoustic signature. Target features were calculated using a harmonic line association (HLA) algorithm, which estimates the fundamental frequency and designates the appropriate harmonics as features of the target. In turn, these features were fed into a classifier for identification and recognition. In addition, research on signature back-propagation was conducted to reduce the effect of acoustic attenuation on the target's signature. With a priori knowledge of the weather conditions, a sound propagation model was used to estimate the attenuation of sound over range and frequency. With proper knowledge of the range calculated from triangulation techniques from various sensor arrays, a measure of the attenuation can be extracted and compensated for to eliminate the effect of propagation.

Impact: The frequency tracker has a significant impact to the Army in the near term, by reducing false alarms and providing robust features for target classifiers. The back-propagation technique will have a large impact to the Army in the long term because it reduces the amount of training data required for a robust identification algorithm.



COMMAND, CONTROL, COMMUNICATION, COMPUTERS & INTELLIGENCE

Center for Geosciences/Atmospheric Research

In FY98, the Congress authorized the funding of Phase III for the Center for Geosciences/Atmospheric Research (CG/AR) at Colorado State University. This phase is intended to focus on transitioning the research results from Phase I and Phase II into the Army, Navy, and Air Force's Environmental Research and Development programs.

The cooperative agreement between the Army and Colorado State University that established the structure to accomplish this technology transition was signed in July 1998. Since that time, we have focused on the establishment of technical connections between the technical staffs at ARL and Colorado State University. ARL scientists have visited the Center and have begun to transfer both research results and actual software into the Army's research program. Scientists from the Center have visited the two ARL research sites: White Sands Missile Range, NM, and Adelphi, MD. These interactions have resulted in ARL plans to include Center technology in future deliveries of the Integrated Meteorological System (IMETS) software, which provides support to the Army soldier in the field. These technical interactions have also led to the establishment of new ARL technical programs in remote sensing, cloud microphysics, and weather modeling to take advantage of the Center's technical contributions.

Impact: As numerical weather prediction, cloud dynamics, weather-hydrological coupling, and remote sensing remain critical areas for all three services, this Center's research will provide weather support to the warfighter in all services.

Battlespace Visualization and Information Processing

Operations on the modern battlefields generate enormous amounts of data and information. A commander's success on the battlefield is directly related to his or her ability to receive comprehensive information in a timely manner and to understand it. ARL has been developing a software infrastructure for battlespace information processing and visualization. The objectives are to develop and integrate several advanced technologies in multimodal human machine interfaces, software agents, and intuitive visualization. Realizing that graphical representation and presentation of information is more easily comprehended, we have integrated 2-D and 3-D map presentations that take a user from one view to another almost instantaneously. Situation understanding is improved by fusing information from a variety of sources and presenting it in suitable modes and alerting the user to the important events. Our research has kept pace with the latest developments in intelligent agent technology and has applied them to assist the commander in managing information.

In FY99, a software agent-based architecture for information processing was developed and demonstrated. Database mediation technology was applied and tested successfully on legacy intelligence and maneuver databases. High-resolution terrain management for imagery submeter elevation extracted features was developed and demonstrated. Speech and natural language technologies were applied to the battlefield visualization system to enable commanders to give spoken commands to navigate on a map.

Impact: For the battlefield commanders, operators, and soldiers, this capability means efficient and easy access to relevant information from a range of databases, sensor suites, humans, and other sources. Legacy systems can also be interfaced through interfacing or wrapping agents. In addition, a variety of special purpose computer programs can be developed with their unique functionality and by prescribing common agent architecture they can be interfaced easily.

Self-Configuring Wireless Mobile Ad Hoc Networks

Army's tactical operations are characterized by a high degree of mobility, which complicates communications among computer networks that assist the tactical forces. Unlike fixed-base commercial operations, the Army faces problems that are peculiar to wireless communication operations and the enemy actions to destroy communication nodes. Participants on the network are constantly changing and it is vitally important to allow friendly forces ready and continual access to the network while denying the adversaries access at all times. These conditions require special protocols and security measures on our networks.

The research objective of MANET—a mobile ad hoc network—is to develop an optimized scalable hierarchical/flat address assignment architecture for dynamic radio network topologies. The research is developing methods for self-configuration and route discovery after sustaining multiple concurrent connection failures, network partitioning techniques, interworking via border nodes, and interoperability with existing and proposed Internet protocols (IPs). The research work keeps pace with developments in multiple access along with network, transport, and security technologies with the aim of adapting these commercial technologies into military networks.

Protocol specifications and proof-of-concept demonstrations were completed of secure mobile multicast internetworking in a dynamically configurable environment. Two multicast routing algorithms were developed. The proof-of-concept demonstrations will use the recently completed ARL Mobile Communications and Networking Testbed.

This project also developed an Internet MANET Encapsulation Protocol network sublayer that is supported by a lightweight inter-router authentication scheme for large-scale mobile networks on the battlefield. This protocol was demonstrated in the laboratory and at CECOM using laptop computer technology.

Impact: The resulting network protocols and security systems will allow Army tactical networks to operate with a predictable quality of service.

Robust Multimedia Compression for Noisy Channels

The civilian sector had made giant strides in the development and application of image and video technologies. The availability of video images received from a variety of strategic and tactical sensors offers tremendous advantages to commanders and soldiers on the battlefield. However, unlike the commercial sector, the bandwidth available to tactical operations is extremely limited. Moreover, the wireless medium is prone to errors introduced by interruptions of the communications channels. Additionally, there is the requirement that the information be encrypted and authenticated so that adversaries can neither gain access to it nor alter it. ARL research is aimed at developing robust, efficient algorithms for the coding, compression, and transmission of images and video over noisy, bandwidth-limited tactical channels.

In FY99, software algorithms were demonstrated for fully functional video coding based on table-look-up vector quantization for use in the tactical wireless networks. Several scholarly papers have been prepared and presented at technical conferences, including the FedLab Annual Symposium. We developed and demonstrated compression algorithms in the laboratory.

Impact: In modern times, the availability of images to the Army has increased at the strategic level allowing a better situational awareness. By improving the Army's ability to communicate those images to tactical theaters where they are most useful provides an enormous edge on the battlefield over the enemy. Likewise, the images and video streams collected by sensors, soldiers, and intelligence sources on the battlefield can be highly valuable in piecing together a comprehensive picture of the battle over a wide theater. Again, this latter capability is dependent on our ability to transfer the information in real time to higher echelons where it can be appropriately fused. ARL research results allow such image transfers up and down the echelons to improve situational understanding.

Energy-Efficient Networks and Acoustic Propagation Studies for Battlespace Sensors

The commercial sector is taking advantage of the nanosciences to create microelectromechanical (MEMS) devices. In its support of WEBS, the Warrior Extended Battlespace Sensors program, ARL is leveraging these technologies to develop microsensors for the battlefield. By enabling the microsensors to communicate among themselves and with commanders on the battlefield, these sensor networks can provide highly valuable information. A network of acoustic sensors has enormous implications for protecting an area or to reconnoiter an enemy force. However, the smallness of their size imposes severe energy budgets on these sensors.

The objective of this project is to optimize the use of the available energy stored in each microsensor and to integrate acoustic propagation as part of the target recognition algorithms. The research examines various tradeoffs arising from the choices of transmission power level, receiver power cycling, and forms of signal processing at the terminal. The study will determine if routing should be performed for minimum power, given medium access scheduling rules. Appropriate control algorithms for determining node neighbor pairings will also be investigated. The project will develop and analyze algorithms that take network priorities into account between nodes based on battery (power) usage and demonstrate the battery lifetime extension efforts of the power-reduction schemes.

A wireless multicasting algorithm was developed that strikes a balance between the benefits of using high power for simultaneously reaching multiple destinations and the benefits of low power for high bandwidth reuse and minimal congestion. Simulations were developed to demonstrate the feasibility of the algorithms. The effects of terrain on power usage were also studied, and simulations pointed out the necessity for incorporating terrain into the routing algorithm.

Impact: The networked sensor technology will revolutionize the surveillance and reconnaissance operations on the battlefield. A large number of miniature sensors can be quickly deployed and configured into a network. They can stay in place and operate undetected for many days and weeks.

Profiler Transition Package

The Profiler (MMS-P) proof-of-concept system is scheduled for transition to the program manager (PM) Night/Vision Reconnaissance, Surveillance, and Target Array (NV/RSTA) at the end of FY99. ARL personnel will complete the integration of the proof-of-concept system into the HMMWV and a trailer, perform field testing, and demonstrate the system at the Senior Fire Support Conference, Ft. Sill, OK. Copies of system documentation, Battlescale Forecast Model software and reports, and field test reports will be handed off to the PM who will be using this data as government-furnished information (GFI) for the selected Profiler (MMS-P) contractor. ARL will provide technical and consultative assistance to the PM in the preparation of requests for proposals, submission evaluation, and subsequent contractor awards.

In FY99, Profiler system documentation, GFI items (i.e., software), test reports, and active consultant support were provided to PM NV/RSTA. The proof of concept was successfully demonstrated at the Senior Fire Support Conference (SFSC) at Ft. Sill, OK, from 12 to 15 April 1999. An end-to-end field test was held from 16 to 19 August 1999. With the assistance of ARL personnel, the PM representative prepared and then briefed the PM NV/RSTA on a two-phase EMD approach. The PM approved the two-phase EMD.

Impact: The resulting system will produce real-time atmospheric soundings that, when provided to the on-board atmospheric model, will provide trajectory and target area MET in close to real-time. This will lead to highly efficient mission planning and use of artillery assets, remove the MET balloon from the battlefield of the twenty-first century, add a first round fire-for-effect *capability, and artillery decision aids on AFATDS and other fire control systems. The bottom line is improved effectiveness of extended range artillery:* one round = one kill.

Information Assurance Program for ARL

ARL was asked to develop a robust and integrated information assurance (IA) program that integrates the existing IA-related activities in ARL and establishes a reason for key Army and DoD IA organizations to partner with ARL.

After AMC requested ARL to develop a pilot program for intrusion detection and monitoring of AMC networks and systems. ARL established an initial monitoring capability at both AMC Headquarters and AMCON.

When the Assistant Secretary of Defense for C³I (ASDC³I) group was tasked to form a Decision Support Activity to coordinate DoD support of Y2K events, it turned to ARL. ARL is providing the following support:

- two prototype mobile command vehicles that will provide backup communications and computing capability during the critical Y2K transition period, group support system technology in the pentagon and White House Y2K command centers to accelerate the staffing of support requests, and
- monitoring of the networks of the Decision Support Activity to detect unauthorized activities.

In addition, ARL has established a key strategic alliance with the U.S. Army Reserves that has resulted in the location of a newly formed Information Operations Center at the Adelphi Laboratory Center.

Impact: This joint AMC-ARL effort will accelerate AMC's efforts to improve its subordinate elements network security. In addition, the partnership is creating a data source to support ARL's research to develop and evaluate new tools and techniques for intrusion detection and monitoring on tactical Army systems. This effort will also allow AMC and the Army Signal Command to stay ahead of the threat to Army networks and computer systems.

The Assistant Secretary of Defense for C³I is effectively leveraging the research of ARL to enhance its ability to effectively manage Y2K-related requests for DoD assistance. ARL will gain valuable insight into how its technologies perform in an operational environment.

The partnership with the Army Reserves will benefit the Army and supports the Total Army concept. The location will allow the Army Reserves to recruit highly qualified information security professionals from both the Baltimore and Washington, D.C., metropolitan areas and to leverage the unique training opportunity afforded by the ARL IA research program and its extensive network connections.

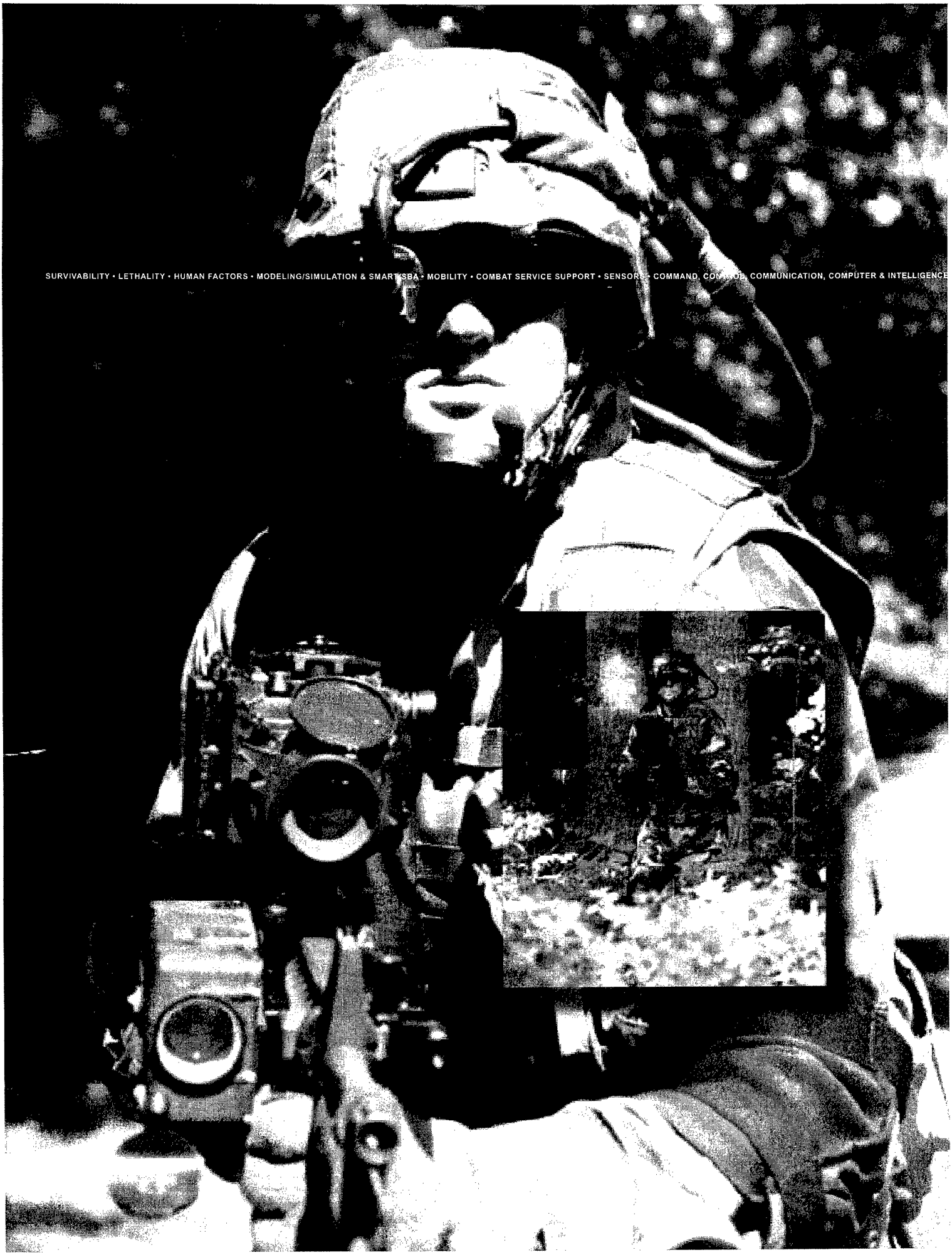
University Partnering for Operational Support

The congressionally directed program, University Partnering for Operational Support (UPOS) at the University of Alaska and Johns Hopkins University, links current university research with operational support requirements within the Army, Navy, and Air Force. A specific benefit of this effort includes tailored theater weather forecasts. A key part of the UPOS program consists of testing deliverables in Commander-in-Charge exercises to evaluate the utility of products developed.

During FY99, ARL assumed responsibility for the research part of the UPOS program that is designed to streamline the process of transitioning space and atmospheric weather research into the operational domain. As a result, ARL has membership on the UPOS Executive Steering Committee that manages the overall program and on the Atmospheric Integrated Project Team (IPT) that reviews the technical progress of the individual atmospheric research projects. Projects are intended to improve Air Force operational weather support to Air Force and Army units. Through the efforts of both the Executive Steering Committee and the Atmospheric IPT, a research team has been identified and the following specific projects have been outlined:

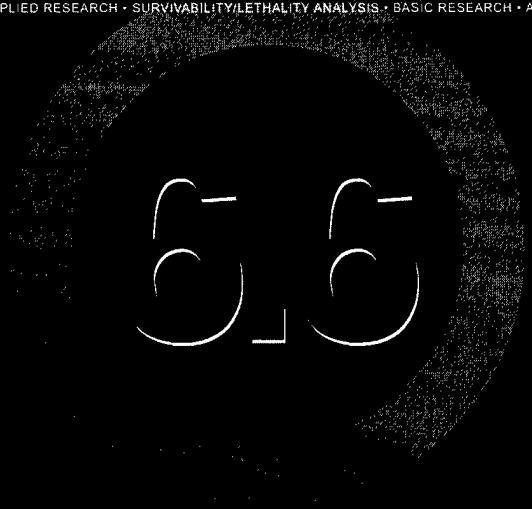
- Enhanced Fine Scale Arctic Numerical Weather Prediction.
- Theater EM Propagation Forecast Maps.
- Atmospheric Correction Based on Forecast of Atmospheric Path.
- Operational Volcanic Plume Forecasting.

Impact: This program provides a mechanism for DoD warfighters to partner directly with university scientists to exploit near-term science and technology advances to solve operational readiness needs in multiple areas including the natural and man-made battlespace environment.


SURVIVABILITY • LETHALITY • HUMAN FACTORS • MODELING/SIMULATION & SMART SBA • MOBILITY • COMBAT SERVICE SUPPORT • SENSORS • COMMAND, CONTROL, COMMUNICATION, COMPUTER & INTELLIGENCE

Survivability/Lethality Analysis

• BASIC RESEARCH • APPLIED RESEARCH • SURVIVABILITY/LETHALITY ANALYSIS • BASIC RESEARCH • APPLIED RESEARCH • MANAGEMENT • SURVIVABILITY • LETHALITY • HUMAN FACTORS • MODELING/SIMULATION



DoD and DA recognize that the survivability and lethality of our systems and soldiers are critical to the success of the Army. ARL is the only source within the Army for fully integrated survivability / lethality analyses across all threats. Such analyses are needed under a DoD regulatory requirement and they help the DA decisionmakers and program managers bring systems through the acquisition process to production and fielding that will be survivable and effective for the Army of the future.

A major mission element for ARL in the Analysis Thrust Area is information warfare vulnerability and survivability analysis for the systems that make up the digitized battlefield. Thus, in meeting this DoD requirement, ARL is helping the Army prepare for the twenty-first century.

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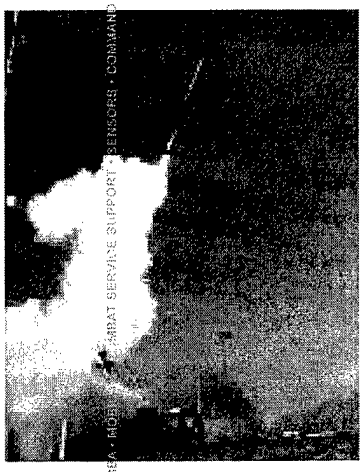
Analysis Thrust Area

ARL is responsible for the development of vulnerability and lethality analyses of all developmental and fielded Army weapon systems and soldiers. The survivability and lethality analysis mission area provides vulnerability, lethality, and survivability assessments of all these weapon systems and soldiers, and integrates them across all battlefield threats and conditions. ARL also develops the tools, techniques, and methodologies to predict battlefield performance, which allow these assessments to be performed efficiently with authoritative results.

Recently, a senior ARL official stated:

> *Survivability and lethality of our systems and soldiers are recognized at DoD and Department of the Army as critical to the success of the Army as we enter the twenty-first century. ARL is unique within in the Army as the only source for fully integrated survivability/lethality analysis across all threats, including information warfare, to help ensure that the systems that program managers and Army decisionmakers bring through the acquisition process to production and fielding will be survivable and effective for the Army of the future.*



Air and Missile Defense

These activities support the technology thrust to ensure system and soldier battlefield survivability and functionality. ARL is developing a Theatre High-Altitude Area Defense (THAAD) system integrated survivability/lethality assessment to provide the Army's independent evaluator, the Operational Test and Evaluation Command (OPTEC), with a comprehensive assessment (and associated analysis support for the System Assessment Report) in support of all major milestone decision reviews. This assessment addresses the complete threat spectrum in a single reference. It also assesses the system's growth potential to meet the operational requirements for initial operational capability given the system's basic technical/tactical design and the available or projected survivability/lethality enhancement options. The system's functional performance and operational effectiveness as denoted via theoretical engineering analyses and supporting tests/simulations is being used to support a classical risk analysis to determine projected system vulnerability risk. A modified form of this vulnerability risk assessment methodology is being applied to enable a similar assessment of system

lethality. This allows, for the first time, the assessment of system vulnerability/survivability (to include weapons effects as well as countermeasure and operational environment effects) via the utilization of a common survivability, lethality, vulnerability (SLV) methodology that is applicable across the full threat spectrum. It is expected that this novel approach will greatly help decisionmakers.

The organizational and analytical structure of the THAAD Survivability, Lethality, and Vulnerability Risk Assessment Report was established and includes system requirements, system description, threat description, survivability analysis methodology (vulnerability risk assessment process), system survivability analysis/assessment (conventional weapons, nuclear weapons, chemical/biological weapons, penetration aid countermeasures, electronic warfare countermeasures, information warfare countermeasures, special operations forces, multiple simultaneous/sequential threat attacks, electromagnetic operational environments [E3], natural operational environments), lethality analysis methodology, and system lethality analysis/assessment (theatre ballistic missile warheads). The analyses of critical supporting integrated system level performance/effectiveness continued. These analyses included the supporting performance/effectiveness analysis of the system's primary ground-based elements (radar, BMC^{4}I, launcher), in-flight interceptor, and ground support equipment. The completion of the supporting subsystem/system analyses and the completion of the final report relied on receipt of the system Engineering and Manufacturing Development design plans (which identified the survivability enhancement options planned to be incorporated) and the MS II Integrated Functional Team (IFT) reports requested via OPTEC.

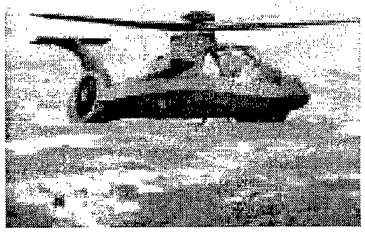
Impact: *ARL's SLV analysis of THAAD will provide the THAAD program managers and Army decisionmakers with early feedback on SLV design options that have both a near-term and a mid-term impact. In addition, ARL anticipates far-term SLV improvements that will address reactive threats, thus providing the interested parties with early insight into Planned Improvement Program options, some of which may be deemed appropriate for current design plans.*

Aviation Systems

These activities support ARL's technology thrusts to ensure system and soldier battlefield survivability and functionality and to identify and reduce information operations vulnerabilities. ARL has been analytically determining the potential vulnerability of the RAH-66 Comanche helicopter to identified and evolving information warfare threats. Deliverables will be a

technical report that addresses system information processing architecture and data flow and that gives a first-order assessment and prioritization of potential information warfare threats and their impact on the Comanche's operation. The results of this scoping effort will then be used to plan and conduct a detailed analytical and experimental assessment of those Comanche systems of highest concern.

ARL reviewed and provided comments for the first draft of the OPTEC Evaluation Analysis Center (EAC) Comanche System Evaluation Plan (SEP) and participated in deliberations with EAC for developing additional requirements. Work continued with EAC to obtain Comanche system briefings and additional information from the Comanche Program Manager's Office and Boeing Sikorsky, the Comanche contractor. The Comanche Information Management System Description and System Architecture were documented and architecture diagrams were completed based on available information. Details of the Aviation Mission Planning System (AMPS)/ Comanche interface design for use in the Information Warfare Vulnerability Analysis were received from the Assistant Product Manager AMPS, Office of the Program Manager, Aviation Electronic Combat.



Acting on advice from ARL, EAC revised the SEP Information Operations (IO) survivability evaluation procedures. These revised procedures are more in line with the ARL Information Systems Survivability Analysis (ISSA) process and more appropriate for the weapon systems platform. A meeting was held at the Boeing Philadelphia facility in June, where representatives from the Comanche PMO, Boeing, and Sikorsky provided briefings on the Comanche platform that addressed information systems issues and architecture questions raised by ARL. System security specialists representing both contractors were in attendance to address the questions. ARL completed documentation of the basic system familiarization effort and architecture diagrams, which were reviewed for accuracy by Boeing and Sikorsky, and a System Familiarization Report was completed. The System Familiarization phase has been completed and is being prepared for incorporation into a single technical report that will use this information to estimate system susceptibility to potential information warfare threats. A draft version of this composite report will be available in December 1999 to support the OPTEC MS II evaluation of Comanche.

Impact: *This system susceptibility information will have a near- and mid-term effect on the understanding of the Comanche's system vulnerability to information warfare threats. Near-term benefits will be an understanding of Comanche information management and its potential susceptibilities, which will enable a follow-on detailed analytical and experimental assessment of those Comanche systems of highest concern. For the mid-term, the information warfare vulnerability data obtained from the follow-on effort will allow the developer to understand potential system information vulnerability and incorporate appropriate vulnerability reduction measures during EMD before MS III in 2006.*

C4I/Information and Electronic Warfare

These activities support ARL's efforts to identify and reduce information operations vulnerabilities. Several Force XXI Battle Command Brigade and Below (FBCB2) test events are being planned for execution in FY99 in preparation for supporting an MS III decision in January 2000. The fielding of FBCB2 hardware and software to the 4th Infantry Division were planned to take place over a two-month period starting in early May 1999. There will be a sequence of laboratory and field testing events following this initial fielding. A technical test is scheduled in May and June, an FTDE in August, and an IOTE in October of 1999. In FY99 the IO and C4I mission area of ARL will support the FBCB2 field test(s) being conducted at both Ft. Huachuca, AZ, and Ft. Hood, TX. ARL will design and fabricate low-cost, low-power EW jammers for the Single Channel Ground and Air Radio System (SINCGARS)-Improvement Program and the Enhanced Position Location and Reporting System (EPLRS) radio. These jammers will replicate the real world threats as identified by each radio's System Threat Assessment Report (STAR). ARL will support these jammers in the field during all planned tests and experiments.

In addition, ARL will support the Communication and Electronics Command (CECOM) Intelligence and Information Warfare Directorate's (I2WD) planned IO/IW wired attacks on the FBCB2 network. ARL will develop attack scripts based on its threat knowledge and research that will be used in the field tests/experiments to address IO threats comprising insider attacks, hacking into the network, and capture/overrun scenarios. ARL personnel will support all aspects of the IO/IW attacks including posttest and postexperiment data analysis and report preparation. ARL will utilize the data from these tests to support both the OPTEC evaluation and the soldier survivability assessment portion of MANPRINT for the MS III.

In FY99 ARL analyzed extensive amounts of data that were collected during the FBCB2 field test that had been held during the previous year. ARL had developed and deployed low-power electronic warfare (EW) jammers against both the SINCGARS radio net and the EPLARS radio net during those tests. The analysis quantified the effects of EW attacks on the tactical Internet (TI) and the reactions of the soldiers to those attacks.

During those same field tests, information warfare (IW) attacks had been launched by ARL analysts against the TI and FBCB2 system replicating the capture of a node on the TI by an enemy force. The attack scripts were developed within ARL's information operations laboratories and deployed using laptop computers. Significant data were collected not only regarding the vulnerability of the TI and FBCB2 to such attacks but also regarding the effectiveness of C^2 protect software developed by the PM IW to thwart such attacks.

These EW and IW events constituted the first tests where such attacks were launched on field deployed Army units. These events mark a significant step forward in the Army's support for realistic operational testing. ARL was an essential and significant participant in this new activity.

Finally, while all the collected data have not yet been completely analyzed, sufficient lessons were learned to prompt the slippage of both the Initial Operational Test and Evaluation (IOTE) and Milestone III decision until some of the deficiencies are corrected. A second field test is now scheduled for December 1999. ARL will again be heavily involved in both the EW and IW vulnerability test events.

Impact: *As a result of ARL experiments and analyses, a multitude of vulnerabilities were identified to both the project manager (PM) FBCB2 and to the TRADOC system manager (TSM). In the near term, the PM has initiated a program to incorporate the ARL-recommended fixes into the overall program. While this has caused schedule delays, in the far-term it will greatly reduce the susceptibility of the system to an IO attack and will ensure that the system successfully meets its fielding requirements.*

Ground Systems

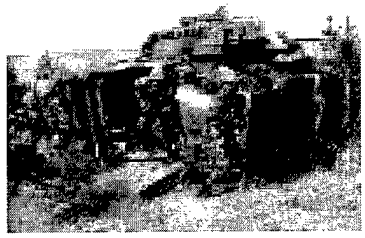
These activities support ARL's technology thrusts to assure system and soldier battlefield survivability and functionality. As directed by the Congress, before a production decision is made, systems meeting certain criteria must undergo live fire test and evaluation (LFT&E). The Bradley A3 Fighting Vehicle is scheduled for a Milestone III (MS III) decision in FY00. ARL is actively participating in the LFT&E of the system. The following efforts have been initiated and will continue through FY 99:

Analysis

- Generate pre-shot predictions.
- Finalize the control damage experiments.
- Conduct damage assessments after each live fire shot.
- Support the overall evaluation phase by providing full view average vulnerability assessments of the Bradley and other systems as deemed necessary.

These efforts will be documented in ARL reports.

The Command and Control Vehicle (C^2V) is also subject to the congressionally mandated LFT&E. ARL also is supporting this program. During FY99, ARL will perform the following experiments and analyses as outlined by the C^2V initial production test (IPT):



- Finalize target description and criticality analysis necessary for estimation of pre-shot predictions.
- Conduct pre-shot predictions of nine events scheduled for test. Both engineering judgement and modeling will be used to estimate performance.
- Support the evaluation efforts that are outlined for LFT&E by the Live Fire Strategy IPT.

In addition to the LFT&E efforts, ARL will also provide the following: soldier survivability assessment (SSV); co-site interference analysis; E^3 vulnerability analysis; and imagery, stereo imagery assessment.

The Bradley A3 LFT&E program completed 18 shots during FY99. ARL completed control damage experiments and generated preshot predictions for these shots. Postshot analyses and full-view averaging were initiated and, once completed will the results given to OPTEC for the System Evaluation Report formulation process. As a result of the Operational Test Readiness Review II for the IOTE that was scheduled for late FY99, the IOTE has been rescheduled for late FY00 or early FY01, and the MS III is now tentatively scheduled for roughly the same timeframe.

Impact: *The Bradley A3 LFT&E has a near-term impact on the Army in that the vulnerability analysis will influence future potential design modifications. Also, it provides an assessment of how the vehicle will perform as currently configured.*

Command and Control Vehicle (C^2V)-Six shots in the C^2V's nine-shot LFT&E series have been completed. The remaining shots are scheduled to be completed in early FY00. The preshot prediction report prepared by ARL was

submitted to HQDA/DOTE in early 3QFY99. Additionally, signature measurement of the C²V were conducted by ARL personnel at White Sands Missile Range, NM, during 3QFY99. Like the Bradley A3, the C²V MS III has been rescheduled. It has been moved from December 1999 to May 2000.

Impact: *The ARL vulnerability analyses of the Command and Control Vehicle will provide an assessment of how the vehicle performs as currently configured and will influence future potential design modifications. This is a near-term impact.*

Munitions

These activities support ARL's technology thrusts to assure system and soldier battlefield survivability and functionality. The FY99 planned efforts in support of the SADARM MS III decision include the completion of

- countermeasures assessment report for IOT&E efforts,
- reports on damage assessments conducted during IOT&E,
- ballistic lethality analysis for SADARM LFT&E,
- E3 oversight assessment report on SADARM, and
- SSv assessment report on SADARM.

Several ARL analysis projects for the sense and destroy armor (SADARM), a fire-and-forget multisensor smart munition designed to detect and destroy countermeasure armored vehicles, were completed in FY99 based on the SADARM IOT&E, which had been conducted with ARL assistance in late FY98. Although the SADARM MS III decision to proceed to full-scale production was cancelled due to results from the operational tests, the tasks below were still completed by ARL in FY99. Results of ARL participation in these activities to a large extent drove the decision to procure several hundred SADARM units and defer major production activity to the SADARM Product Improvement Program. Specific objectives and their status are as follows:

1. SADARM IOT&E investigations in the adverse environments of Alaska by late August 1998.
Status: ARL personnel supported the IOT&E by providing countermeasure expertise and critical ground truth data to TEXCOM to ensure the validity of test results and to correlate test results to environmental and other factors. ARL personnel also conducted on-site damage assessments for all SADARM IOT&E live warhead shots. This effort was successfully completed on schedule.

2. Countermeasures assessment report for IOT&E efforts.
Status: This report has been published and distributed.

3. Reports on damage assessments conducted during IOT&E.
Status: These reports have been published and distributed.

4. Ballistic lethality analysis for SADARM LFT&E.
Status: This analysis was completed and the appropriate reports published and distributed.

5. E^3 oversight assessment and soldier survivability (SSv) assessment reports on SADARM.
Status: These assessments were completed and formal reports were published and distributed.

Final reports on ballistic lethality, damage assessment, E^3, SSv, countermeasures, and target/clutter signature analysis were provided to OPTEC for use in evaluating SADARM performance. These reports were provided in a timely manner to support evaluation time lines for this system. Analyses from these ARL reports were referenced extensively in the SADARM System Evaluation Report (SER).

In addition to planned SADARM support and associated formal reports summarized above, ARL provided significant unplanned measurement and analysis support to TEXCOM for the SADARM IOT&E. Preliminary target signature and damage assessment reports were provided in the field to assist decisionmakers in the conduct of the initial operational tests. These reports proved to be very valuable in evaluating issues that surfaced during the tests. A letter of appreciation for ARL's support was sent from the Director, Operational Test and Evaluation, Office of the Secretary of Defense, for these efforts.

Commensurate with the SADARM program's current direction, an IR/MMW signature characterization of the target array and clutter background for the upcoming SADARM Limited User Tests (LUT) has been completed. These data are being used by OPTEC to finalize test plans for the LUT. This and other LUT activity will be supported through the end of the fiscal year.

Impact: *ARL provided measurement and analysis critical to an understanding of SADARM IOT&E results. IOT&E results were unexpected and not consistent with previous SADARM test results. ARL analysis showed that the environment played a large role in producing the observed IOT&E results. This test and the associated analysis were a milestone in the evaluation community's understanding of the importance of the effects of environment on autonomous munitions performance. As a result, a program to study the effects of the environment on autonomous munitions has been mandated by the evaluation community for SADARM. Environmental studies are being considered for other autonomous munitions programs.*

Management Intiatives

Continuous Improvement

ARL addresses the Army's needs across the continuum—today's Army of Excellence, Force XXI, Army/Joint Vision 2010, and Army After Next (AAN). With its Performance Evaluation Construct and business planning processes, the lab ensures that its technical program is of high quality, relevant to the warfighter, and responsive to its customers. The Technical Assessment Board (TAB) evaluates the quality of the ARL research program. The ARL Board of Directors (BOD), composed primarily of the technical directors of the Army Materiel Command (AMC) Research, Development and Engineering Centers (RDECs), conducts an annual review of ARL's work to ensure ARL supports its principal Army customers. In addition, the Stakeholders' Advisory Board (SAB), chaired by the AMC Commander and made up of ARL's major stakeholders, ensures that the program is responsive to the vision of the Army's senior leadership.

Performance Evaluation

As part of the recently completed Pilot Project for Performance Measurement under the Government Performance and Results Act (GPRA), ARL took on the challenge of solving a problem that has faced the Research and Development (R&D) community for decades: How can one objectively and quantitatively evaluate progress in an R&D program or organization toward proposed outcomes? ARL developed a system to evaluate its performance against a set of objective standards or goals that are related to outcomes specified in the ARL mission statement and strategic plan. This Performance Evaluation Construct is a semiquantitative process

that builds on the three pillars of peer review, customer feedback, and metrics to answer three basic questions about the lab's programs: Is the work relevant? Is it of high quality? Is the organization productive?

As the only R&D organization designated as a GPRA pilot project, ARL has mentored other agencies and activities throughout the government in the techniques it has developed. At the request of the Director of Defense Research and Engineering (DDR&E) and the Assistant Secretary of the Army for Research, Development, and Acquisition (ASARDA), the lab has put much effort into introducing the Construct throughout the Department of Defense (DoD) labs, holding seminars and training sessions, and giving invited talks. Outside DoD, ARL has been a leading participant in the Government Research Roundtable, which has been developing approaches to the various challenges of GPRA for the entire federal technical community. ARL also is a major participant in the National Academies of Science review of the impact of GPRA on the scientific community.

Peer Review

Three and a half years ago, ARL contracted with the National Research Council (NRC) of the National Academies of Science and Engineering to institute the ARL TAB to provide peer reviews of its technical programs. By using the NRC to establish and administer the TAB, ARL is assured of obtaining a review that is completely independent and of the highest possible repute. This candid feedback and the constructive criticism are inherent parts of the peer review process.

The Board, with its six panels aligned by ARL business areas, completed its third year's review in July 1998, and the results were published in the TAB's third public report, *1998 Assessment of the Army Research Laboratory* (National Academy Press, 1999). Overall, the report praised many areas of ARL's technical program, calling out some areas as leading the state of the art, while identifying others as needing improvement. After a series of meetings between the Board and ARL's senior leadership to discuss and clarify these issues, ARL's Director designed an action plan to respond to the points raised by the Board.

The TAB continues to function as ARL had hoped, providing insightful commentary and advice on its technical programs. TAB's fourth review cycle began in spring 1999 with another round of panel visits to the lab that focused on different segments of ARL's overall program as well as the programs of several of its private sector partners. This is in concert with the principle that the Federated Laboratory (FedLab) and other related partnering programs are not separate from the in-house program, but rather are integral parts of it. The visit portion of this fourth cycle is complete. However, as specified under the renewed contract with the NRC, the TAB process has been modified so that formal reports will now be issued every second year. This improved process will allow ARL more time to react to the TAB's recommendations and take steps to recommend course corrections.

During the "nonreport" years, the TAB will still informally give feedback of findings. Thus, the fourth report will be published in January 2001. Annual meetings with the Board and ARL's senior leadership will still be held.

Customer Feedback

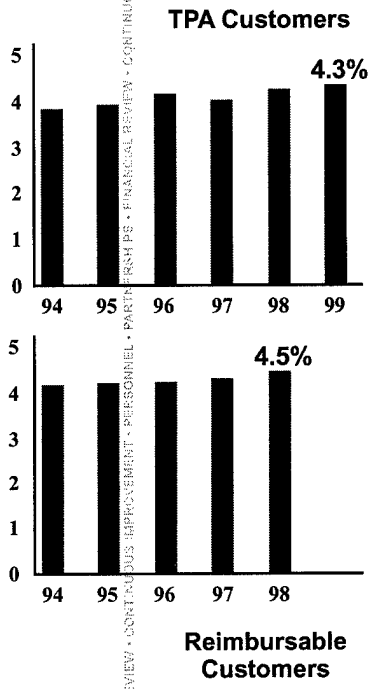
Based on its work under GPRA and research done at the Sloan School of Management at the Massachusetts Institute of Technology (MIT), ARL has identified and segmented its customers and stakeholders and has developed processes to gather feedback on satisfaction from each.

One segment includes those organizations to which ARL provides a specific product, be it a report, an analysis, or a prototype. This group consists of its direct customers, primarily the AMC RDECs, and its reimbursable customers. Since ARL provides a specific deliverable and that deliverable is based on a documented agreement, such as a Technology Planning Annex (TPA) or some other scope of work, the lab has been using a rigorous survey process to capture feedback. Continuing the process that first began in FY94, ARL annually queries its customers, which represent approximately 400 different specific tasks ARL performs, asking for responses on the quality, utility, and timeliness of the product delivered and on the helpfulness of the ARL professional staff members. Customers rank the lab on a 1 to 5 (5 being excellent) scale.

The most recent survey of the TPA customers was completed in June 1999. It had an overall response rate of 74 percent of the 137 surveys sent. As can be seen in the accompanying chart, since FY94, ARL's scores have had an upward trend, now holding around the 4.3 range.

A similar survey is sent to ARL's paying customers, as identified on reimbursable customer orders. The last reimbursable customer survey was done in November 1998 on products delivered in FY98. Based on a response rate of 29 percent of the 193 surveys sent, ARL's score jumped to a 4.5 rating, which is a significant improvement from the previous year.

ARL has also identified other stakeholders who have a major interest in the quality and reliability of its work: the soldiers in the field and the Army's senior leadership. Generally, these groups only see ARL's work after it is embedded in a final product, such as a tank or a helicopter. To obtain feedback from these groups and to increase the feeling of "ownership" by the Army's senior leadership, ARL established the SAB three and a half years ago. The AMC Commander chairs the SAB, whose members include nine senior Army staff members at the three-star (or civilian equivalent) level and the Deputy Commander of the U.S. Army Training and Doctrine Command (TRADOC). This body gives ARL strategic guidance to ensure that its work is tightly coupled to the Army's needs and that it is being responsive to the leadership. The SAB also pulls together the other parts of the Performance Evaluation Construct by hearing briefings from both the TAB and the BOD leadership. This allows the Army's senior leadership to gain a holistic picture of how well its corporate laboratory is performing.



The SAB held its fourth meeting at Adelphi in July 1999. Lieutenant General James M. Link, AMC Deputy Commander (sitting in for the newly appointed AMC Commander, General John G. Coburn), chaired the session, which was attended by the members of the Army's senior leadership or their principal representatives. Briefings and demonstrations were presented and discussions were held concerning how ARL is meeting the challenges of increasing and changing workload and decreasing budgets and staff. Particularly, the members discussed ARL's intentions to continue its various reinvention initiatives of expanding the FedLab concept and concentrating its efforts on core business functions. All the SAB members had high praise for ARL, its work, and its people and they pledged their support as the lab goes through these difficult times.

Metrics

People frequently look for quantifiable metrics as indicators of performance, but such an approach has consistently proven unworkable and inappropriate in R&D. Counting achievements like patents and papers measures activity, but does not necessarily reflect the quality or utility of the work done. Even so, metrics do indicate the functional or operational health of the organization, so ARL collects data on over 50 metrics for two basic purposes (see the supplement to this review for specifics).

The first purpose is simply to track information that the lab is required to report to higher headquarters or that might be useful to know, such as financial and personnel data, as well as activity indicators, including the number of patents and papers. As long as these numbers are within some accepted bounds, either defined by regulation or by common sense, they are tracked by the functional office chiefs and only reported to the Director on an exception basis.

Second, the metrics data provide a tool for the Director to use to improve the research environment of the laboratory. For example, the Director believes that the number of guest researchers working on-site at ARL should be at a certain level. Likewise, he believes that the educational level of the work force should be high. Therefore, the Director has chosen to closely observe a subset of these roughly 50 metrics that ARL tracks. He implements such goals by placing them in the performance standards of his senior management team, thus coupling ARL's metrics system to individual performance and giving those leaders the incentive to move the parameters in line with his expectations. This was favorably noted in a recent U.S. General Accounting Office (GAO) report on this topic.*

In FY99, 15 metrics were on the Director's "short list." Of those, ARL met or exceeded the goal for 5 and came close in the others, indicating that productivity as reflected by these output measures increased in spite of workforce downsizing, internal reorganizations, and site consolidations.

**Performance Management: Aligning Employee Performance With Agency Goals at Six Resuts Act Pilots*, U.S. General Accounting Office, GAO/GGD-98-162 (September 1998).

Personnel

Personnel Demonstration

In the FY95 Defense Authorization Act, Congress empowered the National Performance Review Science and Technology (S&T) Reinvention Laboratories to design and experiment with alternative civilian personnel systems. The purpose of the resulting personnel demonstration program is to enhance the effectiveness of DoD laboratories by allowing greater managerial control over personnel functions and, at the same time, expand the opportunities available to employees through a more responsive and flexible personnel system.

Since the *Federal Register* posting on 4 March 1998 and the conversion to the alternative civilian personnel system in June 1998, ARL has completed two rating cycles: the first from 7 June 1998 through 30 January 1999 and the second from 1 February 1999 through 30 September 1999.

Awards

Department of the Army Achievement Medal for Civilian Service

William M. Corr
Ronald W. Mihalcin

Commander's Award for Civilian Service

Mary E. Chandler
Ronald C. Hargrove
Benjamin E. Holberg
Richard A. Huang
Betty A. Irby
Mark D. McKitrick
Frederick W. Perry
Robert E. Rothenbuhler
Sam W. Shelton III
Jose Torres
Lavern Harris
Barbara A. Hansen
Richard R. McMahon

Superior Civilian Service Award

Jagdish Chandra
Judith S. Clarke
Felipa C. Coleman
Shirley A. Eller
Sophia Harrison
Megan A. Reichelderfer
Kathy Lynn Leiter
Leonard I. Huskey
Robert H. Rosen

Distinguished Service Award

Andrew Crowson
Bruce M. Fornoroff
Lawrence D. Johnson
Robert E. Singleton
Robert W. Whalin

Exceptional Civilian Service Award

John W. Lyons

Meritorious Civilian Service Award

Robert W. Whalin

Other Awards

ARL Fellow—Bruce J. West (Army Research Office (ARO)), Mitra Dutta, John E. Rowe, and Michael A. Stroscio

PASREG Award of Excellence—Roy Weinsten (ARO)

Association of Old Crows Life Achievement Award—Thomas W. Reader

Excellence Medallion—Michael A. Stroscio

Institute of Electrical and Electronics Engineers (IEEE) Electrotechnology Transfer Award—Michael V. Scanlon

STAR Award—HSTSS Integrated Product Team—awarded ARL members: Bill P. D'Amico, Jr., and Larry W. Burke

Bowie State University Honorary Law Degree—James D. Gantt

U.S. Army Wilks Memorial Award—Robert L. Launer

Society of Photooptical Instrumentation Engineers (SPIE) Fellow—John M. Pellegrino and Gary Anderson (ARO)

Defense Standardization Program Outstanding Performance Award—Kathy M. Bamberg

Baltimore Federal Executive Board (BFEB) Silver Award—Linda D. Baldwin and Thomas M. Kendall

Bronze Award—Robert H. Rosen, Jeanne T. Angelini, and Jane C. Forties

Partnerships

ARL has continued the development of education partnership agreements with Historically Black Colleges and Universities/Minority Institutions (HBCU/MI). Among the many HBCU/MIs with which we have such agreements are Alcorn State, Clark Atlanta, Hampton, Howard, Lincoln, New Mexico State, and North Carolina Agricultural and Technical State universities; City College of the City University of New York; Southern University;

Southwestern Indian Polytechnic Institute; University of California at Los Angeles (UCLA); University of Texas at El Paso; and the University of the Virgin Islands.

ARL has contractual relationships with six HBCU/MIs totaling over $10 million. This is 32 percent of our contractual effort with all higher educational institutions—far over the 5 percent statutory requirement. Eight HBCU/MI partners participate in FedLab, the Army High-Performance Computing Research Center (AHPCRC), and other partnership arrangements. Currently, ARL employees serve as adjunct professors at three HBCU/MI: Clark Atlanta, New Mexico State, and Tuskegee universities.

ARL has continued the Science and Technology Academic Recognition System (STARS), established during FY96, which is a training and development program designed to reach talented students at HBCU/MI who are enrolled in a science, engineering, or mathematics curriculum. In FY99, ARL recruited an additional four STARS fellows, bringing the total number to eleven. The program offers up to $20,000 for tuition and expenses during the senior undergraduate year and up to $30,000 for each of two years of graduate school. This year's recruitment represents a total of over $1M that ARL has committed to STARS recipients.

Through educational partnership agreements, ARL scientists and engineers support student mentoring, work with faculty and students under internship programs, judge science fairs, serve on business advisory and economic development groups, and donate surplus equipment, adding vitality to the technology and education community. In FY99, ARL had established 43 educational partnership agreements and donated more than $2.1 million of scientific equipment to educational institutions.

Technology Transfer Office

Central to the ARL in-house research program is the need to locate and develop valuable technology and creative ideas regardless of the source. The ARL Technology Transfer Office promotes and manages the exchange of scientific and technological knowledge between laboratory and industry, academia, and allied governments. As the world businesses, governments, and technology race through change, merger, and divestiture, flexible programs allow all parties to participate in their own self-interests and enable ARL to meet compelling mission needs by leveraging the talents and investments of others.

Domestic Technology Transfer

ARL continued an active Domestic Technology Transfer program during FY99. Creative partnerships through cooperative R&D agreements (CRDA) encourage outside businesses and university organizations to share in the discovery of and investment in technologies. Patent License Agreements (PLAs) (see supplement) permit ARL to share important mission breakthroughs with industry, pushing the technology to commercial applications.

Spin-on, spin-off, and dual-use application of technologies in core mission areas continues to grow in importance. Actively managing, protecting, and marketing key technologies, such as materials, robotics, sensors, individual protection, and pollution prevention, allows the technology to advance by bringing in new partners. Participation in the Aberdeen Proving Ground (APG) Science and Technology Board initiatives, regional technology councils, and the national FedLab consortium technology transfer programs provides a supportive environment for technology development. A business-like entrepreneurial culture is taking hold in ARL.

Using a CRDA, a team of ARL engineers successfully transferred a new laser-forming rapid-prototyping technology: the LASFORM℠ process and system. Commercialized by AeroMet, a subsidiary of MTS Systems Corporation and both of Eden Prairie, Minnesota, AeroMet was founded in 1997 mainly to commercialize ARL's vision and direction in rapid prototyping. The LASFORM℠ system is the largest rapid prototyping system in the world. The process is a flexible one-step method. With the use of computer numerical control instructions, a powdered metal is deposited as molten droplets on a metallic substrate located beneath the focused beam. The resulting near-net geometry of parts provides many advantages when compared to conventional metal-forming systems.

The United States Advanced Battery Consortium, made up of General Motors Corporation, Daimler-Chrysler Incorporated, Ford Motor Company, and the Electric Power Research Institute, signed a CRDA with ARL in FY99. The agreement seeks to use ARL-invented additives for electrolytes to be used in lithium-ion batteries for the future electric car. The batteries must operate under high temperatures and extreme conditions. The significance and benefits to a growing portable power society and a mobile-powered Army cannot be underrated.

In FY99, 18 new CRDAs were added to the portfolio. There are 98 active CRDAs. ARL also manages 31 active PLAs. Technology transfer programs and partnerships with outside R&D organizations play a central role in ARL's technology development strategy.

Small Business Innovation Research

Through the Small Business Innovation Research (SBIR) program, the Army accesses technological advances of small, innovative firms with fewer than 500 employees. The Army provides funding, per public law (U.S.C. 102 to 564), for high-quality research or R&D proposals of innovative concepts to solve Army/DoD-related scientific or engineering problems, especially those concepts that also have high potential for commercial use. ARL has been a consistent leader in the Army SBIR program.

The program consists of three stages or phases. Phase I awards enable recipients to demonstrate the concept feasibility of their proposals. During FY99, ARL awarded 30 new Phase I contracts at about $70,000 each. Successful Phase I recipients are invited to submit Phase II proposals. Phase II

contracts are awarded to those recipients who are evaluated the highest. During Phase II, the recipients establish the proof of principle and produce a prototype. Contractors are also expected to use this 24-month Phase II period to establish commercial interest for Phase III, which uses no SBIR money. ARL awarded 16 new Phase II contracts during FY99 at $730,000 each.

The ARL SBIR budget for FY99 was over $14 million. The ARL SBIR program consistently receives awards and recognition. During FY99, the ARL SBIR program manager was recognized for being a member of the DoD SBIR Process Action Team that was given the "Hammer Award." This award was presented for "contributions to building a government that works better and costs less." During FY99, two ARL-sponsored Phase II companies were honored as recipients of the prestigious *R&D Magazine*, R&D 100 Awards, as being responsible for "one of the 100 technologically significant new products of the year." The companies were Radiometrics Corp., of Boulder, CO, honored for the development of a microwave atmospheric profiler, and Materials Modification, Inc., of Fairfax, VA, honored for the development of the plasma pressure compaction apparatus. Both of these companies typify the small business "can-do" attitude and reflect on the partnership between ARL scientists and engineers and small businesses to satisfy Army needs and develop a product for the commercial market.

International Technology Transfer

Cooperation with allied defense establishments leverages the domestic defense R&D investments. ARL has a vigorous international program with 43 active and proposed agreements (28 Data Exchange Agreements (DEAs) and 15 project arrangements (PAs)). In addition, an extensive cooperative activity exists through multilateral forums, such as The Technical Cooperation Panel (TTCP) and NATO and Senior National Representative (SNR). ARL has set the standard for executive management of its international programs by establishing Technology Working Groups with its major partners, first with France and Israel and then in 1998 with the United Kingdom Ministry of Defense (UK-MOD), initiating a similar annual executive review of ARL/UK programs.

Two new DEAs and two PAs were established in FY99 to enable and promote cooperative research programs with allies in selected technology areas where their strengths complemented ARL and offered good leveraging opportunities. These include materials science research and increased reliability power sources with the UK, robotics with Israel, and light armor with Australia.

In FY99, a strong multinational and industrial robotics program has led to the successful completion of the DEMO II program and the initiation of its follow-on DEMO III. The sniper detection program with the UK and France is developing and evaluating systems for immediate fielding with Army units deployed in peacekeeping operations. In ballistics, electrothermal chemical combustion was jointly investigated with Germany and novel armor concepts with the UK.

Management Intiatives

The Assistant Secretary of the Army for Acquisition, Logistics, and Technology recognized ARL's special role in fostering international cooperative R&D programs by giving ARL chair responsibility in the annual revision of Annex E, "Global Technology Capabilities & Trends," of the *Army Science and Technology Master Plan.* The 1998 edition produced under ARL's direction took a major step forward by being published on a CD in menu-driven hypertext with a greatly enhanced database for worldwide technology assessment. In 1999, this database was further enhanced and the Office of the Secretary of Defense (OSD) recognized the Army's lead in this area by participating in the Army annual review.

In FY99, ARL's cooperative activities with the UK were significantly strengthened as shown by the growing synergy between ARL and the UK's newly established Defense Evaluation and Research Agency (DERA), its research programs closely paralleling those of ARL. There were vigorous interactions both at the executive management level, because of shared interests in outsourcing options, and at the technical level, with close collaboration in specific technology areas. A new Information Exchange Annex (IEA) on Materials Technology was established, and its first collaborative "Home-On-Home" meeting was held at Aberdeen Proving Ground, MD, in August. The initial exchange showed considerable promise for a strong long-term collaborative relationship between ARL and DERA across a spectrum of technical areas, bolstered by the two state-of-the-art materials research laboratories recently constructed in the respective countries.

In recognition of ARL's world-class research programs, numerous executive-level visits from defense laboratories of foreign allied countries occurred in FY99, including UK, Canada, Sweden, Poland, Taiwan, Australia, and Korea.

Financial Review

Resources

ARL continues to reduce costs, cut staffing levels, and improve business processes in keeping with DoD initiatives. In addition, ARL was faced with a number of challenges during FY99. Many of these challenges may have long-term and far-reaching financial management implications. Endeavoring to improve its strategic position for responding to the significant changes anticipated over the next few years, ARL continued studies on base support levels and participates in the AMC Working Capital Fund Proposal Evaluation Integrated Process Team. In FY99, ARL was pleased to welcome the addition of the Army Research Office as part of the ARL family. Additional FY99 changes included the release of approximately $1.3M of Y2K (year 2000) funds to help alleviate ARL Y2K costs. Several directorates projected shortfalls early in FY99, and directorate solvency was closely monitored. Some reallocation of funds was necessary to cover shortfalls as a result of a shortage of incoming customer work. Reducing staff was not necessary to remain solvent in FY99 and to meet financial goals. Throughout the year, the laboratory adjusted workloads and curbed discretionary spending in both overhead and technical areas. These corrective actions allowed ARL to successfully operate within budget and exceed the DoD's established obligation goals.

Revenue

Revenue	FY98 actual	FY99 projected	$ Millions FY99 change	FY99 actual	FY00 projected
RDTE					
6.1 Basic Research	94.8	90.5	6.0	96.5	97.2
6.1 FedLab	26.3	21.7	–0.1	21.6	24.9
6.2 Applied Research	126.1	108.5	9.1	117.6	148.1
6.3 Advanced Development	0.0	0.0	3.8	3.8	1.0
6.4 Demonstration/Validation	0.7	0.0	0.3	0.3	0.0
6.6 Technology Analysis	62.9	64.2	3.9	68.1	68.0
6.6 Management Support	38.5	37.6	2.4	40.0	9.1
6.7 Operational System Development	1.1	1.4	0.1	1.5	1.2
RDTE Subtotal	350.4	323.9	25.5	349.4	349.5
Customer Reimbursable	102.3	103.7	–3.2	100.5	115.3
OSD	72.7	71.0	–2.8	68.2	65.9
DARPA	56.7	57.0	17.6	74.6	64.1
OMA/Procurement	34.3	27.2	1.6	28.8	74.7
Total Revenue	616.4	582.8	38.7	621.5	669.5

Note: This profile includes ARO and MSRC/HPC data in each FY.

ARL's total revenue increased 0.8 percent ($5.1M) from FY98 ($616.4M) to FY99 ($621.5M). Increases were realized in Defense Advanced Research Projects Agency (DARPA) ($17.9M), while decreases were realized in RDTE mission funding ($1.0M), customer reimbursable funding ($1.8M), OSD funding ($4.5M), and operations and maintainance, Army (OMA) ($5.5M). Note FY98 data have been adjusted to include ARO and the Major Shared Research Center/High Performance Computing program for comparison purposes.

ARL's mission program took two general reductions in FY99. The first reduction was the distribution of nonspecific congressional adjustments that the Department of the Army (DA) distributes across all projects. A total of $8.7M was taken from ARL's program to reduce work performed by Federally Funded Research and Development Centers (FFRDCs) and consulting contractors to adjust for revised inflation assumptions, to adjust civilian personnel costs, and to provide funding for SBIR and Small Business Technology Transfer (STTR) programs. A second general reduction of $4.1M was taken as a result of OSD revised inflation adjustments and the need to divert funds for high-priority contingency requirements. ARL received $25.8M of SBIR and STTR funding to cover new and ongoing proposals. ARL received $1.3M in supplemental appropriation for Y2K conversion and $0.7M for maintenance and repair. The financial impact of FY99 congressional actions on specific ARL programs is shown below.

ARL Program	$M
Science Problems with Military Application	–$7.9
Historically Black Colleges and Universities	+$4.0
Defense Research Science	–$4.2
University and Industry Research Centers	–$3.0

Hardened Materials	+$3.0
Software Agent Program	–$1.8
Passive Millimeter Wave Camera	+$3.0
AAN Applied Research (new start)	–$5.5
Photonics Research	+$2.5
Electric Gun	–$3.6
Rural Health	+$3.0
Chemical Hazardous Material Disposal	+$1.5
Computer Information Sciences Technology	+$1.7
University Partnering for Operational Support	+$3.0
Information Warfare Vulnerability Assessment	+$4.0

An important aspect of ARL's transformation into a FedLab is the increased focus on core business areas. Focusing ARL's resources on key technology areas rather than spreading them thinly over a broad technology base allows ARL to concentrate on new and emerging technologies that meet the needs of Force XXI, Army/Joint Vision 2010, and AAN. The following provides a breakout of FY99 revenue by business area.

Business Area	$M
University Research	$160.4
Human Engineering	$26.1
Information Systems Technology	$49.5
Sensors and Electronic Devices	$111.3
Survivability/Lethality Analysis	$52.6
Weapons and Materials Research	$98.7
Vehicle Technology Center	$9.2
Corporate Information and Computing (HPC)	$54.4

Operating Expenses

Total operating expenses increased 0.8 percent ($5.1M) from FY98 ($616.4M). All categories had increases in response to increased revenue. Increases occurred in labor, $2M; other internals, $0.7M; and contracts and actions with other government agencies, $2.4M. Costs for general and administrative (G&A) overhead decreased by $4.4M with indirect overhead increasing by $2.1M. No large non-BRAC infrastructure improvements occurred in FY99.

Laboratory Overhead

ARL overhead is funded through a combination of appropriated overhead funds and a distribution of costs to each technical mission and customer-funded labor hour. If the appropriated funding remains constant, every dollar saved through efficiencies will reduce the cost distributed to the benefiting technical mission and customer-funded programs. Because of revenue constraints, management continues to aggressively identify areas that could be deferred or reduced.

General and Administrative Overhead

	$ Millions					Projected	
	FY94	**FY95**	**FY96**	**FY97**	**FY98**	**FY99**	**FY00**
Distributed (burden & customer)	41.9	40.2	32.3	41.1	35.2	31.5	38.1
Appropriated	52.5	47.6	50.0	39.6	40.3	39.6	38.1
Total	94.4	87.8	82.3	80.7	75.5	71.1	76.2

G&A overhead are costs that are less than 100 percent attributable to a specific mission, but benefit all ARL's technical and customer programs. The G&A budget is funded through a combination of appropriated funding and cost distribution to technical and customer-funded programs. Included are corporate management, base operations, and general installation maintenance functions. In FY99, the actual G&A expenditures were $71.1M, or $0.7M above the original approved budget. These increases can be attributed to supplemental appropriation funding of $0.7M received for maintenance and repair/minor construction initiatives. Labor savings from the FY99 approved budget were attributed to continued attrition occurring mainly in the Chief of Staff organization and the decision to limit hiring. Savings are projected for labor and internal costs in future years as management continues to aggressively identify areas where overhead can be reduced. The projected $5.1M increase of G&A costs in FY00 reflects an urgent need to significantly upgrade ARL's communications infrastructure for the start of the next millennium.

Indirect Overhead

$ Millions						Projected
FY94	**FY95**	**FY96**	**FY97**	**FY98**	**FY99**	**FY00**
38.1	33.1	34.6	29.0	31.3	33.4	28.1

Note: Figures for FY97 and 98 have changed to reflect program readjustment.

Indirect overhead are costs that are 100 percent attributable to the mission but do not produce the primary research effort. These expenses include supervision above the first-line supervisor and administrative support at the directorate level. These expenses are distributed to the technical mission and customer-funded programs. Indirect costs increased by $2.1M in FY99 primarily because of (1)budget support transfers to our technical dir ectorates ($1.7M) and (2) Test and Evaluation Command (TECOM) transfers of base support costs to TECOM's ARL tenants at APG and White Sands Missile Range (WSMR) ($1.2M). The projected decrease in FY00 of $5.3M is due to efficiencies made within the lab's technical directorates by reducing contracts and actions with other government agencies, equipment purchases and maintenance, supplies, and long-term training costs.

Management Intiatives

Financial and Program Initiatives and Significant Accomplishments

ARL continued to upgrade automation in the program and budget areas. Emphasis was placed on enhancing dissemination of information, guidance, and consistency of data with and through ARL's intranet-linked web site. This site provides easy access to management and technical directorates for up-to-date information on program and budget planning, formulation, and execution. As of the end of FY99, the following information was available on line: current funding guidance, S&T planning information, ARL congressional descriptive summaries, Director's Research Initiative Program, Advanced Concepts and Technology (ACT) II program, ARL 6.2 Roadmaps, ARL Modeling and Simulation program, and Science and Technology Objectives (STO) guidance. A new Windows-based interactive web site was implemented for the Technology Planning Database (TPD), the primary source for out-year programming information, thus allowing easier data entry, decreased server usage, better data accessibility, and reduced directorate workload.

The BuyIt program was successfully implemented at ALC, APG, and WSMR to include a Standard Operations and Maintenance and Research and Development System (SOMARDS) interface for certification of funds. The addition of an automated feed of labor data from the Integrated Facilities System (IFS) to SOMARDS greatly increased the timeliness and quality of labor data reported.

The ARL Director continued the Director's Research Initiative Program in FY99. This program encourages innovative research within ARL that exhibits high potential for payoff. Proposals are competitively awarded using laboratory mission funding. In FY99, proposals totaling $3.5M were awarded.

FY99 Budget Execution Highlights

ARL received 69 percent of the anticipated FY99 Research, Development, Test, and Evaluation (RDTE) mission program at the beginning of the fiscal year. DA held 25 percent, or $76M, of the program to adjust for general congressional reductions, plus $2.4M was on hold for PBDs 604 and 605. Another $23.9M was held for potential congressional changes to specific programs (congressional worst-case scenario) and $15.8M for congressional increases. The Revised Approved Program (RAP) of $81.3M was released in January. ARL's mission program exceeded the DA obligation and disbursement goals throughout the year. At year-end, ARL's FY99 RDTE program was 99.3 percent obligated against the DA goal of 95 percent; disbursements were 66 percent against the DA goal of 57 percent. The FY99 OMA program was 100 percent obligated, meeting the DA goal of 100 percent. The FY99 OSD program was 98 percent obligated, exceeding the DA goal of 96 percent.

Organizational Information

Organizations	Directors	Program $M	Workforce	S&Es
Army Research Office	Dr. Jim C. I. Chang Phone: 919-549-4203 Fax: 919-549-4348 email: arodir@aro-emh1.army.mil	160.4	99	42
Corporate Information and Computing Directorate	Dr. N. Radhakrishnan Phone: 410-278-6639 Fax: 410-278-5075 e-mail: amsrl-ci@arl.mil	54.4	119	35
Human Research and Engineering Directorate	Dr. Robin Keesee Phone: 410-278-5800 Fax: 410-278-0505 e-mail: rkeesee@arl.mil	26.1	189	124
Information Science and Technology Directorate	Dr. James Gantt Phone: 301-394-2100 Fax: 301-394-5420 e-mail: jgantt@arl.mil	49.5	187	149
Sensors and Electron Devices Directorate	Dr. John Pellegrino Phone: 301-394-2002 Fax: 301-394-5410 e-mail: pell@arl.mil	111.3	338	266
Survivability/ Lethality Analysis Directorate	Dr. James Wade Phone: 505-678-1196 Fax: 505-678-1198 e-mail: jwade@arl.mil	52.6	289	223
Vehicle Technology Directorate	Dr. Wolf Elber Phone: 757-864-3956 Fax: 757-864-7796 e-mail: w.elber@larc.nasa.gov	9.2	99	69
Weapons and Materials Research Directorate	Dr. Ingo May Phone: 410-306-0646 Fax: 410-306-1043 e-mail: amsrl-wm@arl.mil	98.7	410	306

Management Intiatives

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